(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 July 2001 (26.07.2001)

PCT

(10) International Publication Number
WO 01/54077 A1

(51) International Patent Classification⁷: G07D 7/12

(21) International Application Number: PCT/US00/28030

(22) International Filing Date: 10 October 2000 (10.10.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/489,453 21 January 2000 (21.01.2000) US

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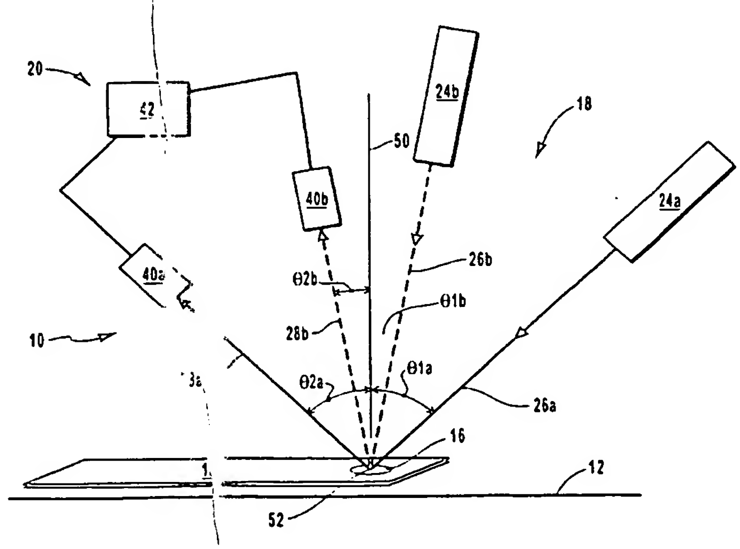
(81) Designated States *(national)*: AU, CA, CN, JP, KR.

(84) Designated States *(regional)*: European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: AUTOMATED VERIFICATION SYSTEMS AND METHODS FOR USE WITH OPTICAL INTERFERENCE DEVICES



(57) Abstract: An automated verification system for authenticating an object having an optical security feature includes an optical system, a transport staging apparatus, and an analyzing device. The optical system includes one or more light sources that are capable of generating either narrowband or broadband light beams. The transport staging apparatus cooperates with the light sources and is configured to position the object such that one or more of the light beams strike a portion of the object where the security feature should be located. The analyzing device receives the light beams reflected or transmitted from the object and is adapted to analyze the optical characteristics of the light beams at varying angles and/or wavelengths to verify the authenticity of the object.

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AUTOMATED VERIFICATION SYSTEMS AND METHODS FOR USE WITH OPTICAL INTERFERENCE DEVICES

BACKGROUND OF THE INVENTION

1. The Field of the Invention

The present invention relates generally to systems and methods for determining the authenticity of objects. More particularly, the present invention is related to systems and methods for automatically verifying the authenticity of an item by scanning for a security feature having predetermined spectral reflectance characteristics.

2. The Relevant Technology

In modern society, various conventional methods are utilized to trade goods and services. There are, however, various individuals or entities that wish to circumvent such methods by producing counterfeit goods or currency. In particular, counterfeiting of items such as monetary currency, banknotes, credit cards, and the like is a continual problem. The production of such items is constantly increasing and counterfeiters are becoming more sophisticated, particularly with the recent improvements in technologies such as color printing and copying. In light of this, individuals and business entities have a desire for improved ways to verify the authenticity of goods exchanged and/or currency received. Accordingly, the methods used to prevent counterfeiting through detection of counterfeit articles or objects must increase in sophistication.

Methods used to scan currency and other security items to verify their authenticity are described in U.S. Patent Nos. 5,915,518 and 5,918,960 to Hopwood et al. The methods described in the Hopwood patents utilize ultraviolet (UV) electromagnetic radiation or light sources to detect counterfeit currency or objects. Generally, the tested object is illuminated by UV light and the resultant quantity of reflected UV light is measured by way of two or more photocells. The quantity of UV light reflected from the object is compared against the level of reflected UV light from a reference object. If the reflectance levels are congruent then the tested object is deemed authentic.

The methods in the Hopwood patents are based on the principle that genuine monetary notes are generally made from a specific formulation of unbleached paper, whereas counterfeit notes are generally made from bleached paper. Differentiation between bleached and unbleached paper can be made by viewing the paper under a source of UV radiation. The process of detection can be automated by placing the suspect documents on a scanning stage and utilizing optical detectors and a data analyzing device,

with associated data processing circuitry, to measure and compare the detected levels of UV light reflected from the tested document.

Unfortunately, there are many problems with UV reflection and fluorescence detection systems, that result in inaccurate comparisons and invalidation of genuine banknotes. For example, if the suspect object or item has been washed, the object can pick up chemicals which fluoresce and may therefore appear to be counterfeit. As a result, each wrongly detected item must, therefore, be hand verified to prevent destruction of a genuine object.

Other conventional methods to detect counterfeit objects utilize magnetic detection of items which have been embossed or imprinted with magnetic inks, and/or image verification of images on the object. Unfortunately, magnetic inks are available to counterfeiters and can be easily applied to counterfeit objects, and image verification systems can be fooled by counterfeit currency made with color photocopiers or color printers, thereby reducing the effectiveness of these anti-counterfeiting approaches.

Other verification methods utilize the properties of magnetic detection to detect the electrical resistance of items which have been imprinted with certain transparent conductive compounds. These methods are, however, relatively complicated and require specialized equipment which is not easily available, maintainable, or convenient to operate, particularly for retail establishments or banks that wish to quickly verify the authenticity of an item.

Various items such as banknotes, currency, and credit cards have more recently been imprinted or embossed with optical interference devices such as optically variable inks or foils in order to prevent counterfeiting attempts. The optically variable inks and foils exhibit a color shift which varies with the viewing angle. While these optical interference devices have been effective in deterring counterfeiting, there is still a need for an accurate and convenient measuring system to verify that an item is imprinted with an authentic optical interference device.

With current advances in technology, new techniques are needed to battle a counterfeiter's ability to fabricate counterfeit objects. Accordingly, there is a need to provide authentication systems that extend the arsenal available to governments, business retailers, and banks to verify the authenticity of an item.

SUMMARY OF THE INVENTION

In accordance with the invention as embodied and broadly described herein, systems and methods are provided for automatically verifying the authenticity of an object by scanning for an optical interference security feature in the form of an optical interference device, such as a color shifting device having predetermined spectral reflectance or transmittance characteristics. Various objects such as currency, banknotes, credit cards, and other similar items imprinted or embossed with an optical interference device can thereby be authenticated.

A color shifting security feature exhibits both a characteristic reflectance spectrum and a spectral shift as a function of viewing angle, which can be utilized by the verification systems of the invention to determine the authenticity of an object. A verification system of the invention can be automated by placing the items to be verified on a transport stage which moves the items in a linear fashion for scanning.

The verification systems of the present invention generally include an optical system, a transport staging apparatus, and an analyzing device. The optical system includes one or more light sources that are capable of generating either narrow band or broadband light beams. Cooperating with the light sources is the transport staging apparatus, which is configured to position the object such that one or more of the light beams strike a portion of the object where a security feature should be located. The analyzing device receives the light beams reflected or transmitted from the object and the security feature, and is adapted to analyze the optical characteristics of the light beams reflected or transmitted by the object at varying angles and/or wavelengths to verify the authenticity of the object.

In one method for verifying the authenticity of an object according to the present invention, at least one light beam at a first incident angle is directed toward an object to be authenticated. The object is positioned such that the light beam is incident on a portion of the object where an optical interference security feature should be located. The light beam is directed from the object along one or more optical paths, such as by reflection or transmission, and one or more optical characteristics of the light beam are analyzed to verify the authenticity of the object. The optical characteristics can be analyzed by comparing the spectral difference between two light beams reflected or transmitted at different angles from the object against a reference spectral shift, or by comparing the spectral shape of at least one light beam reflected or transmitted from the object against a reference spectral shape.

These and other aspects and features of the present invention will become more fully apparent from the following description and appended claims, or may be learned by the practice of the invention as set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to more fully understand the manner in which the above-recited and other advantages and objects of the invention are obtained, a more particular description of the invention will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments of the invention and are not therefore to be considered as limiting of its scope, the invention will be described and explained with additional specificity and detail through use of the accompanying drawings in which:

Figure 1 is a schematic depiction of an automated verification system in accordance with one embodiment of the present invention;

Figure 2 is a graphical representation of the reflection intensity as a function of position on a banknote imprinted with an optical interference security feature;

Figure 3 is a schematic depiction of an automated verification system in accordance with an alternative embodiment of the present invention;

Figure 4 is a schematic depiction of an automated verification system in accordance with another embodiment of the present invention;

Figure 5 is a schematic depiction of an automated verification system in accordance with another embodiment of the present invention;

Figure 6 is a schematic depiction of an automated verification system in accordance with an alternative embodiment of the present invention;

Figure 7 is a schematic depiction of an automated verification system in accordance with a further embodiment of the present invention;

Figure 8 is a schematic depiction of an automated verification system in accordance with an alternative embodiment of the present invention;

Figure 9 is a schematic depiction of an automated verification system in accordance with another embodiment of the present invention;

Figure 10 is a schematic depiction of an automated verification system in accordance with an alternative embodiment of the present invention;

Figure 11 is a graphical representation of various reflectivity intensities of various stations in the embodiment of Figure 10;

Figure 12 is a schematic depiction of an automated verification system in accordance with another embodiment of the present invention;

Figure 13 is a schematic depiction of an alternate configuration of the embodiment of Figure 12;

Figure 14 is a schematic depiction of an automated verification system in accordance with an alternative embodiment of the present invention;

Figure 15 is a schematic depiction of an automated verification system in accordance with a further embodiment of the present invention; and

Figure 16 is a schematic depiction of an alternate configuration of the embodiment of Figure 15.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to systems and methods for automatically verifying the authenticity of an object by scanning for an optical interference security feature having predetermined optical spectral characteristics, whether reflectance or transmissive characteristics. The invention is particularly useful in testing the authenticity of various objects such as banknotes, currency, credit cards, and the like which have been imprinted or embossed with an optical interference security feature such as a color shifting pigment, ink, foil, or bulk material, such as but not limited to plastic.

Recently developed color shifting pigments, inks, foils, and bulk materials used as security features have significantly reduced the ability to counterfeit goods, currency, banknotes, credit cards, and the like. Color shifting pigments, inks, foils, and bulk materials are formed from multi-layer thin film interference coatings that are very complicated to manufacture. As such, it is extremely difficult for counterfeiters to duplicate the effects of such color shifting security features. Additionally, in the case of banknotes and currency, the specific color shifting pigment or ink formulation is available only to legitimate manufacturers and specific governmental agencies, such as the U.S. Treasury. These color shifting pigments and inks exhibit a visual color shift which varies with the viewing angle. The amount of color shift is dependent on the materials used to form the layers of the coating and the thicknesses of each layer. Furthermore, at certain wavelengths the color shifting pigments and inks exhibit the property of higher reflectance with increased viewing angle. Examples of specific compositions of such color shifting pigments or inks which can be utilized in a security feature are described in U.S. Patent No. 5,135,812 to Phillips et al., the disclosure of

which is incorporated by reference herein. Since the optical effects from the color shifting pigments or inks are repeatable and unique for each specific type of coating structure, the resulting color shift, reflectance, and/or transmittance of an authentic security feature can be measured and used as a standard or reference to test suspect security features placed on items or objects.

The systems and methods described herein allow for a simple and convenient verification of authenticity by scanning the optical characteristics, such as spectral reflectance or transmittance and/or the degree of spectral shift with angle using one or more light beams incident upon the security feature. The optical characteristics and/or spectral shift is compared with stored reference data to verify the authenticity of the security feature and hence the object.

Referring to the drawings, wherein like structures are provided with like reference designations, Figure 1 is a schematic depiction of an automated verification system 10 in accordance with one embodiment of the present invention that can be utilized for validating the authenticity of an object that should include an optical interference security feature. The verification system 10 measures the spectral shape of the reflectance spectrum for an optical interference security feature 16 on an object 14 in or order to verify its authenticity. It can be appreciated, however, that verification system 10 may also use the spectral shape of the transmittance spectrum, whether alone or in combination with the reflectance spectrum to verify the authenticity of security feature 16.

The security feature 16 can take the form of various optical interference devices, such as optically variable inks, pigments, or foils including color shifting inks, pigments, or foils; bulk materials such as plastics; cholesteric liquid crystals; dichroic inks, pigments, or foils; interference mica inks or pigments; goniochromatic inks, pigments or foils; diffractive surfaces, holographic surfaces, or prismatic surfaces; or any other optical interference device which can be applied to the surface of an object for authentication purposes. Other suitable optical interference devices which combine diffractive or holographic surfaces with color shifting inks or foils are disclosed in a copending U.S. patent application, filed on January 21, 2000 by Roger W. Phillips et al. and entitled "Optically Variable Security Devices", the disclosure of which is incorporated by reference herein. Additional suitable optical interference devices are disclosed in copending U.S. patent application Serial No. 09/351,102, filed on July 8,

1999 and entitled "Diffractive Surfaces with Color Shifting Backgrounds", the disclosure of which is incorporated by reference herein.

The object 14 on which security feature 16 is applied can be selected from a variety of items for which authentication is desirable, such as security documents, security labels, banknotes, monetary currency, negotiable notes, stock certificates, bonds such as bank or government bonds, commercial paper, credit cards, bank cards, financial transaction cards, passports and visas, immigration cards, license cards, identification cards and badges, commercial goods, product tags, merchandise packaging, certificates of authenticity, as well as various paper, plastic, or glass products, and the like.

The verification system 10, as depicted in Figure 1, includes a transport staging apparatus 12 for carrying an object 14 to be authenticated, an optical system 18 for illuminating object 14, and an analyzing system 20 for analyzing the features of a reflectance spectrum. The verification system 10, therefore, is adapted to authenticate object 14 through analyzing the spectral shape of the reflectance spectrum for security feature 16. Generally, system 10 verifies the authenticity of security feature 16 by comparing the reflectance spectra of security feature 16 at two different reflection angles θ_{2a} and θ_{2b}.

The verification system 10 includes an optical system 18 that has two or more light sources such as broadband light sources 24a, 24b. Broadband light sources 24a, 24b generate light in a range of wavelengths, such as from about 350 nm to about 1000 nm, to illuminate in a collimated fashion security feature 16 located on object 14. Suitable devices for light sources 24a, 24b include tungsten filaments, quartz halogen lamps, neon flash lamps, and broadband light emitting diodes (LED). It can be appreciated that system 10 may be modified to include only one light source 24, for example, including a mirror and a beam splitter or using bifurcated fibers fed from a common or single source.

The light sources 24a, 24b respectively generate a first beam 26a and a second beam 26b that are transmitted to an intersection point 52 at differing incident angles θ_{1a} and θ_{1b} with respect to normal 50. Alternatively, first beam 26a and second beam 26b may be transmitted to different spots that do not intersect. Instead, beams 26a, 26b focus upon two separate spots that lie upon the longitudinal axis of transport staging apparatus 12 which object 14 passes along. In this configuration, beams 26a, 26b need not be activated and deactivated in sequence, but rather beams 26a, 26b may be continuously activated.

Light beams 26a, 26b are directed from security feature 16 along two different optical paths having angles θ_{2a} and θ_{2b}, respectively, toward analyzing system 20, as defined by beams 28a, 28b. As depicted, beams 28a, 28b are reflected from security feature 16, however, it may be appreciated that the optical paths may include transmitted beams, as depicted in Figure 10. Discussion will be made, with respect to reflectance angles, however, a similar discussion may be made with respect to transmittance angles. It can be appreciated, however, that operation of the present invention may be possible when θ_{1a} equals θ_{2a} and θ_{1b} equals θ_{2b}. The particular values of incidence angles θ_{1a} and θ_{1b} of beams 26a and 26b, along with the resultant reflection angles θ_{2a} and θ_{2b} of light incident upon analyzing system 20 are important features of the present invention since the incident angles θ_{1a} and θ_{1b} directly effect the verification method. Accordingly, system 10 is configured such that incident angle θ_{1a} and reflection angle θ_{2a} are in a range from about 30° to about 80° from a normal 50, and preferably from about 40° to about 60°. The incident angle θ_{1b} and reflection angle θ_{2b} are in a range from about 0° to about 30° from normal 50, and preferably from about 5° to about 15°. It is preferable that θ_{1a} not equal θ_{2a}, and that θ_{1b} not equal θ_{2b}, or stated another way, measurement of reflected beams 28a, 28b should be performed at a different angular orientation relative to normal 50 than the incident angle of the incident light. By so doing, the gloss effects of light reflecting from the gloss surface of security feature 16 are mitigated.

The analyzing system 20 of the embodiment of Figure 1, includes a first optical detector 40a and a second optical detector 40b which are operatively connected to a data analyzing device 42. The detectors 40a, 40b preferably have the form of spectrophotometers or spectrographs. The detectors 40a, 40b are used to measure the magnitude of the reflectance as a function of wavelength for the security feature being analyzed. Detectors 40a, 40b measure the reflectance from security feature 16 on object 14 over a range of wavelengths at two different angles and combine the reflectance data at each wavelength to generate a spectral curve for each reflection angle.

The detectors 40a, 40b may comprise, for example, a linear variable filter (LVF) mounted to a linear diode array or charge coupled device (CCD) array. The LVF is an example of a family of optical devices called spectrometers which separate and analyze the spectral components of light. The linear diode array is an example of a family of photodetectors that transduce a spatially varying dispersion beam of light into electrical signals that are commonly displayed as pixels. Together, the spectrometer and the photodetector comprise a spectral analyzing device called a spectrophotometer or

spectrograph. It can be appreciated, therefore, that various other spectrometer and photodetector combinations and configurations may be used to obtain the desired reflectance data. For example, and not by limitation, in one configuration, detectors 40a, 40b are grating, prism, filter, or interferometer based spectrometers whose spectral output is scanned or detected photometrically by photometric array devices such as a linear diode array that may or may not be coupled to an image intensifier. In another configuration, detectors 40a, 40b use photographic film that is developed and coupled to a scanning microdensitometer. In yet another configuration, detectors 40a, 40b operate by scanning the optical spectrum across a slit mounted in front of a single photodetector, such as a photodiode or photomultiplier, in the manner of a traditional scanning spectrophotometer. Still yet another configuration of detectors 40a, 40b operate by scanning a photodetector mechanically or optically across the output face of a spectrometer or LVF. Yet another configuration of detectors 40c, 40b operate by scanning an interferometer's interference pattern across a photodetector followed by electronic transformation to a spectrum of the analyzed light. All of these combinations are known in the art as methods for converting a light into an electronically displayed graph called a spectrum and are collectively called spectrophotometers and spectrographs by those skilled in the art. The detector 40a is configured to receive light beam 28a reflected at a reflection angle θ_{2a} which is preferably close to incident angle θ_{1a}, while detector 40b is configured to receive light beam 28b reflected at a reflection angle θ_{2b} which is preferably close to incident angle θ_{1b}. As such, detectors 40a, 40b are each configured at a particular angular orientation which corresponds to the respective reflection angle of the light received by the detector. As shown in Figure 1, detector 40a is at a greater angular orientation than detector 40b.

Communicating with detectors 40a, 40b is data analyzing device 42. Data analyzing device 42 electronically processes the data received from detectors 40a, 40b and compares the same with stored reference data to verify the authenticity of the security feature. The data includes electronic signals representative of the spectral shift of light reflected from the security feature at two different angles. Specifically, each detector 40a, 40b measures the reflectance over a range of wavelengths to generate a spectral curve for each light beam 28a, 28b reflected at angles θ_{2a} and θ_{2b}, respectively. The data analyzing device 42 uses a microprocessor and additional circuitry to analyze the spectral curve generated by each detector 40a, 40b to verify the authenticity of security feature 16. For example, software is used to compare the spectral curves measured with reference spectra

stored in a database of analyzing system 20. If the features of the measured spectra substantially coincide with the feature of reference spectra, then the item is deemed to be genuine. Therefore, data analyzing device 42 may indicate to a user whether the tested object is authentic or potentially counterfeit. As with detectors 40a, 40b, there are various types of data analyzing devices known to those skilled in the art that are capable of performing the desired function, such as application specific logic devices, microprocessors, or computers.

The security feature 16 of the embodiment depicted in Figure 1 is generally formed from a high-precision optical interference device applied to object 14 as a pigment, ink, foil, or bulk encapsulant such as plastic. As the angle of incident light on security feature 16 is varied, the peak and trough wavelengths in a reflectance vs. wavelength profile changes. This provides a contrast between the low and high reflectance spectral features (*i.e.*, peaks and troughs) produced by security feature 16, which is used by verification system 10 to determine the authenticity of security feature 16.

Physics dictates that the reflectance and transmittance spectra of optical interference devices shift toward shorter wavelengths with increasing viewing angle. In a method utilized in system 10 to verify the authenticity of object 14, a wavelength for each incident light beam 26a, 26b from light sources 24a, 24b is preselected which is near a peak or trough of the known reflectance vs. wavelength profile for security feature 16. For example, assuming angle θ_{2a} is greater than angle θ_{2b}, if the wavelength of beams 26a, 26b from light sources 24a, 24b is near the value corresponding to a peak in the reflectance vs. wavelength profile (*i.e.*, a reflectance maxima), then the ratio of reflectance at angle θ_{2a} to reflectance at angle θ_{2b} (*i.e.*, the reflection ratio) will be less than one. Conversely, if the wavelength of beams 26a, 26b from light sources 24a, 24b is near a trough of the reflectance vs. wavelength profile (*i.e.*, a reflectance minima), then the ratio of reflectance at angle θ_{2a} to reflectance at angle θ_{2b} will be greater than one. This latter case of selecting a wavelength near a trough of the reflectance vs. wavelength profile is advantageous in that most materials actually decrease in reflectance at increasing incident angles, whereas the color shifting pigments, inks, foils, and bulk encapsulants utilized for security imprinting have the unique property of increasing reflectance with increasing incident angles. As such, this latter case provides the advantage of making the verification more certain.

To be able to measure the change in reflectance with varying incident angles it may be desirable to interrupt beam 26a while allowing passage of beam 26b and vice versa. As such, each of the embodiments described herein is capable of operating either with continuous beams 26a, 26b or alternating beams 26a, 26b from different angular orientations. Therefore, one method of achieving alternating beams 26a, 26b is through interrupting power to one of light sources 24a, 24b or through the use of a barrier device, such as an optical chopper or electromechanical shutter. It can be appreciated that various other configurations of devices to interrupt beams 26a, 26b are known by one skilled in the art.

For color shifting pigments and inks such as those described in Phillips '812 that has been applied in a manner to give a low-gloss surface, it is preferred that incident angles θ_{1a} and θ_{1b} be each approximately equal to the respective reflection angles θ_{2a} and θ_{2b}. It will be appreciated that reflection angles θ_{2a} and θ_{2b} need not equally correspond to the respective incident angles θ_{1a} and θ_{1b}, as the angle of reflection can change depending on the type of optical interference security feature employed.

In operation of verification system 10, object 14 such as a banknote which has been affixed with security feature 16, is placed upon transport staging apparatus 12. The light sources 24a, 24b generate light beams 26a, 26b respectively that are directed to be incident upon intersection point 52 on the surface transport staging apparatus 12. The object 14 is moved in a linear fashion through intersection point 52, such that security feature 16 passes linearly through intersection point 52. Since object 14 moves past intersection point 52, verification system 10 has the ability to scan a line-shaped area of security feature 16 rather than a spot. The light beams 28a, 28b reflected from security feature 16 are incident upon detectors 40a, 40b, which simultaneously measure the reflectance at the two different reflection angles θ_{2a} and θ_{2b}, respectively, yielding the reflectance spectrum at each angle. One technique to analyze such data is to pick one wavelength from the spectrum and compare the reflectance at the one wavelength measured at both angles θ_{2a} and θ_{2b} thus yielding the reflection ratio for that wavelength. The reflection ratio of the reflected light beams at reflection angles θ_{2a} and θ_{2b} is compared with the reference reflection ratio for a known authentic security feature to determine authenticity. For example, a genuine security feature might be configured to produce a higher reflectance at θ_{2a} than at θ_{2b}, resulting in a predetermined reflection ratio, whereas a counterfeit would show either the same or lower reflectance at θ_{2a} compared to θ_{2b}, resulting in a differing reflection ratio. It may be appreciated, that

verification system 10 may operate in the transmittance mode rather than the reflectance mode to verify the authenticity of security feature 16.

According to another aspect of the presently depicted invention, verification system 10 includes transport staging apparatus 12. The transport staging apparatus 12 provides a means for positioning an object such that a beam of light is incident on a portion of the object where a security feature should be located. Numerous configurations for performing the desired transporting and positioning functions can be employed by transport staging apparatus 12. For example, transport staging apparatus 12 can include a belt or conveyor that carries and/or holds object 14 in the required orientation during the authentication process, moving object 14 in a linear fashion past optical system 18. Such a belt or conveyer may be deployed in either a high speed or low speed configuration to provide continuous verification of multiple objects, items or articles. In another configuration, transport staging apparatus 12 provides for stationary positioning of an object 14 in verification system 10. Various other structures may also function as a transporting and positioning means, and are known by those skilled in the art.

Conventional verification systems that measure a spot of a security feature are significantly less accurate than systems of the present invention since the measurement might be at a position on the item other than the security feature. This occurs because it is nearly impossible to guarantee that the ink or other material forming the security feature exists at a precise set of coordinates on the item being tested. In contrast, the verification systems of the present invention provide the ability to determine automatically the location of the security feature, thereby providing increased detection accuracy.

Figure 2 depicts schematically a typical plot of reflection intensity as a function of linear position on a scanned item such as a banknote imprinted with a security feature. Such a plot further represents a component of the reflection data detected by detectors 40a, 40b and data analyzing device 42 as the banknote passes through intersection point 52 in system 10. As shown in Figure 2, a change in the reflection intensity, which is usually an increase, occurs at the location of the security feature on the banknote. If the features of the measured spectra substantially coincide with the features of the reference spectra, then the item is deemed to be genuine.

While the above description with respect to Figures 1 and 2 has focused on authentication of a document such as a banknote, it will be appreciated by those skilled

in the art that the systems, methods, and apparatus of the present invention may be utilized in various other situations where verification of a security feature is desired such as, but not limited to, verification of credit cards, passports, commercial paper, goods, identification badges, product tags, or the like.

Referring to Figure 3, an automated verification system 110 in accordance with another embodiment of the present invention is depicted. The verification system 110 includes some of the features described above with respect to system 10, including a transport staging apparatus 12 for carrying an object 14 to be authenticated. The verification system 110, however, is adapted to authenticate object 14 through analyzing the angle shift or color shift of a single wavelength band of electromagnetic radiation reflected from optical interference security feature 16.

Verification system 110 generally includes a transport staging apparatus 12 for carrying an object 14, an optical system 118, and an analyzing system 120. Optical system 118 includes two light sources; a first light source 124a and a second light source 124b that are helium neon lasers or laser diodes, capable of generating monochromatic and collimated light beams 126a, 126b, respectively. The light sources 124a, 124b can take various other forms so long as they are capable of generating a monochromatic light beam. For example, light sources 124a, 124b can be monochromators or broadband sources taken through a narrow bandpass filter.

Analyzing system 120 includes a first optical detector 140a and a second optical detector 140b which are operatively connected to a data analyzing device 142. In contrast to detectors 40a, 40b of the embodiment represented in Figure 1, detectors 140a, 140b may take the form of semiconductor photodiodes that are capable of detecting light reflected from security feature 16. Detectors 140a, 140b convert the reflectance characteristics of the reflected beams of light, beams 128a, 128b, from security feature 16 and transmit the data to data analyzing device 142. It will be appreciated by one skilled in the art that various other detectors are capable of performing the desired function, for example, spectrophotometers and spectrographs, such as, but not limited to photomultiplier tubes, CCD arrays, pyroelectric detectors, or photo-thermal detectors.

During operation of verification system 110, first beam 126a is generated by light source 124a which is incident upon object 14 at an incident angle θ_{1a} that is different than an incident angle θ_{1b} of a second beam 126b generated by light source 124b. The beam 126a is reflected toward a detector 140a along a first optical path at a reflection angle θ_{2a}, depicted as beam 128a, while beam 126b is reflected toward a detector 40b along a

second optical path at a reflection angle θ_{2b}, depicted as beam 128b. As described previously, each verification system of the present invention may operate in a transmittance mode rather than a reflectance mode. Therefore, the first and/or second optical paths of beams 128a, 128b may be transmittance paths through object 14. The data analyzing device 142 operatively connects to detectors 140a, 140b and electronically processes the data related to spectral shift characteristics received from detectors 140a, 140b to verify the authenticity of a security feature 16 on object 14.

Referring to Figure 4, an alternate embodiment of the presently described invention of Figure 3 is depicted. The majority of the features discussed with respect to verification system 110 also apply to automated verification system 160. The verification system 160 includes some of the features described above with respect to system 110, including a transport staging apparatus 12 for carrying an object 14 to be authenticated. The significant difference between verification system 160 and verification system 110 is optical system 168. As depicted in Figure 4, optical system 168 includes a single light source 174, such as a helium neon laser or a laser diode that is capable of generating a monochromatic and collimated light beam 176. The light source 174 can take other forms so long as it is capable of generating a monochromatic light beam. For example, light source 174 can be a monochromator or a broadband source taken through a narrow band pass optical filter.

In optical communication with light source 174 is a beam splitter 182, which separates light beam 176 into two beams, a first light beam 176a and a second light beam 176b. The first beam 176a is directed toward transport staging apparatus 12 at a first incident angle θ_{1a} relative to normal 50, while second beam 176b is reflected to a mirror 180 that reflects second beam 176b towards transport staging apparatus 12 at a second incident angle θ_{1b}. The beam splitter 182 can split light beam 176 in various ways, such as, but not limited to, polarization components, bandwidths, intensities, or the like. As such, beam splitter 182 can be a polarizing beam splitter, a cubic beam splitter, partial reflector, or the like.

Further, it shall be appreciated that the combined function of beam splitter 182 and mirror 180 could alternatively be provided by a bifurcated fiber optic system that divides the incident light beam 176 and allows redirection of one or more intensity beams such as 176a and 176b.

The beam 176b is reflected from mirror 180 toward transport staging apparatus 12. Various mirrors 180 are appropriate for performing this desired function and are

known by one skilled in the art. The mirror 180 is positioned in optical communication with transport staging apparatus 12 such that beam 176b is reflected from mirror 180 toward transport staging apparatus 12 at a second incident angle θ_{1b} different from the incident angle θ_{1a} of first beam 176a. Nevertheless, beam 176b reflected from mirror 180 falls upon security feature 16 on object 14 at substantially the same point as beam 176a at an intersection point 52 as shown in Figure 4. Although beams 176a, 176b are shown meeting at intersection point 52, it may be appreciated that beams 176a, 176b need not meet, but may impinge upon transport staging apparatus 12 at different points upon the same longitudinal path that object 14 passes along transport staging apparatus 12.

The analyzing system 170 includes similar detectors and data analyzing devices as those previously discussed in verification system 110, to thereby authenticate security feature 16. Accordingly, analyzing system 170 includes a first optical detector 190a and a second optical detector 190b which are operatively connected to a data analyzing device 192. Detectors 190a, 190b convert the reflectance characteristics of the reflected beams of light, beams 178a, 178b, from security feature 16 and transmit the data to data analyzing device 192.

Referring to Figure 5, an alternate embodiment of an automated verification system 210 is depicted. The verification system 210 includes substantially all the features described above with respect to verification system 160, including a transport staging apparatus 12 for carrying object 14 to be authenticated. The significant differences between verification system 160 and verification system 210 is the specific configuration of optical system 218 and analyzing system 220. Analyzing system 220 is configured to receive the two or more reflected or transmitted beams 228a, 228b from object 14 and combine them into a single beam 228 that is utilized to verify the authenticity of object 14. Therefore, analyzing system 220 includes a mirror 230 and a beam splitter 232. As depicted, beam 228b is reflected from security feature 16 at angle θ_{2b} toward mirror 230. Various types of mirror 230 are possible and known by one skilled in the art. Beam 228b reflected from mirror 230 is incident upon beam splitter 232 that combines beam 228b and beam 228a reflected at θ_{2a} into a single beam 228. The beam splitter 232 can combine beams 228a, 228b in various ways, such as, but not limited to, according to the polarization components, bandwidths, intensities, or the like. As such, beam splitter 232 can be a polarizing beam splitter, a cubic beam splitter, a partial reflector, or the like. It may be appreciated that in another configuration the function of beam splitter 232 and

mirror 230 could be provided by a bifurcated fiber optic system to combine the reflected beams 228a, 228b.

It is understood that the functions and structures of verification systems 160 and 210 may be combined into a single verification system 260, as depicted in Figure 6. Verification system 260 includes a optical system 268 that uses a mirror 280 and a beam splitter 282 to split the beam 276 into two beams 276a, 276b. Additionally, verification system 260 includes an analyzing system 270 that also uses a mirror 284 and a beam splitter 286 to recombine reflected beams 278a, 278b into a single beam 278 that is directed towards detector 290 and data analyzing device 292.

Depicted in Figure 7 is another alternate embodiment of automated verification system 110. The majority of the features discussed with respect to verification system 110 also apply to verification system 310. The system 310 includes a transport staging apparatus 12 for carrying an object 14 to be authenticated. An optical system 318 generates a light beam 326 having a single wavelength or a small number of discrete wavelengths. An analyzing system 320 is provided for verifying the angular reflectance or transmittance of light beam 326 reflected or transmitted from a security feature 16 on object 14. This system replaces the collection of light from two or more light sources and achieves multiple incident angles with the use of an optical scanning device such as a rotating mirror as the only moving part.

As shown in Figure 7, verification system 310 is adapted to verify the angular reflectance of light beam 326, however, one skilled in the art may modify the structure of verification system 310 to verify the angular transmittance. Optical system 318 includes a light source 324, such as a helium neon laser or a laser diode that is capable of generating a monochromatic and collimated light beam 326. As previously discussed, light source 324 may have various other forms so long as it is capable of performing the above defined function. In this embodiment, it is particularly important that light source 324 generates a very well collimated beam 326, because analyzing system 320 uses the angular reflectance rather than optical spectrum to determine authenticity of security feature 16. Another beneficial characteristic of using a highly collimated beam 326 is that beam 326 is very bright and has a high intensity.

Optically communicating with beam 326 is an optical scanning device in the form of a rotatable mirror 330, and a cylindrical lens 332. Rotatable mirror 330 has a generally polygonal shape such that rotation of mirror 330 varies the angular orientation of beam 326 leaving one of the mirror surfaces. Rotation of mirror 330 is controlled by

a timing circuit (not shown) that allows complete control of the angle of incidence and reflection of beam 326 at any instant. It can be appreciated that various other optical scanning configurations can be used in place of rotatable mirror 330, such as a rotating or oscillating plane mirror, galvanometric optical scanner, electrooptical beam deflector, acoustooptical beam deflector, microelectromechanical system scanners (MEMS) such as a digital mirror display (DMD), or the like.

Light reflected from mirror 330 is incident upon cylindrical lens 332. Lens 332 has a generally cylindrical form having an input surface 334 and an exit surface 336. Beam 326 which is reflected from rotatable mirror 330 is transmitted by lens 332 to be incident upon security feature 16 of object 14 at varying incident angles θ_{1a}-θ_{1n}. It can be appreciated that one skilled in the art may identify various other configurations of lens 332 so along as the lens is capable of performing the desired function, *i.e.*, transmitting an incident beam of light 326 upon security feature 16.

Analyzing system 320 includes a detector 340 and data analyzing device 342. Detector 340 has the form of a single linear detector or photodiode array. Alternatively, a plurality of detectors may be utilized, as well as various other types of spectrophotometers and spectrographs known to those skilled in the art.

Detector 340 receives beam 328 which is reflected from security feature 16 at varying reflected angles θ_{2a}-θ_{2n}, due to the varying angles of incidence θ_{1a}-θ_{1n} of beam 326. Detector 340 measures the intensity of the reflected light at given reflected angles θ_{2a}-θ_{2n}, and transmits the requisite data to data analyzing device 342. Data analyzing device 342 is operatively connected with the timing circuit (not shown) to control the rotation of mirror 330 such that the specific angle of incidence θ_{1a}-θ_{1n} is known at any instant. By comparing the incident angle θ_{1a}-θ_{1n} to the reflected angle θ_{2a}-θ_{2n} and detected intensity, data analyzing device 342 may calculate the reflectance intensity as a function of incident angle. This is then used to verify the authenticity of object 14.

In operation, light source 324 generates beam 326 which is directed to mirror 330. Beam 326 is reflected from rotatable mirror 330 at varying angular orientations, for example ± 30 degrees relative to a normal of the reflected surface of rotatable mirror 330. As such, beam 326 reflected from mirror 330 sweeps from + 30 degrees to -30 degrees relative to the normal of a mirror surface as mirror 330 rotates. The sweeping beam of light is incident upon an input surface of cylindrical lens 332. Cylindrical lens 332 transmits each sweeping beam 326 to a specific spot on transportation stage system 16 where security feature 16 of object 14 is to pass. The angular orientation of beam 326 is

continually varying and therefore the angle of incidence θ_{1a}-θ_{1n} and angle of reflection θ_{2a}-θ_{2n} of beams 328 and the associated optical path continually change. These changes in angle of reflection θ_{2a}-θ_{2n} are detected and used to verify the authenticity of security feature 16. Specifically, since security feature 16 is an optical interference device, the reflected light varies with both angle and wavelength in a manner characteristic of the device and different from the counterfeit.

Various other configuration of the above described embodiment of the present invention are possible and known by one skilled in the art. For example, another configuration of verification system 310 includes multiple light sources that are capable of generating various monochromatic beams of light having differing wavelengths. As such, adjacent facets of polygonal mirror 330 reflect a different wavelength of light to allow reflectance to be measured at several different discrete wavelengths simultaneously. In another configuration, angle of incidence θ_{1a}-θ_{1n} is close to or surrounds both sides of normal 50. As such, the plane of incidence must be separated from the direction of normal 50 to allow detection of the reflected light. To achieve this, analyzing system 320 is skewed relative to normal 50, therefore both cylindrical lens 332 and rotatable mirror 330 are skewed by an equal but opposite degree of tilt relative to the plane containing normal 50.

Referring to Figure 8, an automated verification system 360 in accordance with another embodiment of the present invention is depicted. The verification system 360 includes some of the features described above with respect to system 10, including a transport staging apparatus 12 for carrying an object 14 to be authenticated. The verification system 360, however, is adapted to authenticate object 14 through analyzing the spectral shape of the optical spectrum of light reflected from security feature 16 at a single reflectance angle.

Discussion herein will be directed to the various structures and functions associated with verification through use of reflectance spectrum, however, a similar discussion may be made with respect to the transmittance spectrum.

As discussed above, since security feature 16 is generally formed from a high-precision optical interference device, there is a great contrast between the high and low reflectance spectral features, *i.e.*, peaks and troughs. Additionally, the spacing of the peaks and troughs, and their respective wavelengths, is predictable and repeatable, such that the spectral shape or profile of each security feature can serve as a "fingerprint" of the physical structure of the optical interference device. For example, in a five layer

multi-layer thin film interference device such as described in Phillips '812 having the design metal$_1$-dielectric-metal$_2$-dielectric-metal$_1$ ($M_1DM_2DM_1$), the peaks (H) and troughs (L) have wavelengths that are related through the following mathematical formulae:

λ_{L1}	$\cong$	Quarter Wave Optical Thickness	λ_{H1}	$\cong$	$\lambda_{L1}/2$
λ_{L2}	$\cong$	$\lambda_{L1}/3$	λ_{H2}	$\cong$	$\lambda_{L1}/4$
λ_{L3}	$\cong$	$\lambda_{L1}/5$	λ_{H3}	$\cong$	$\lambda_{L1}/6$
λ_{L4}	$\cong$	$\lambda_{L1}/7$	λ_{H4}	$\cong$	$\lambda_{L1}/8$
λ_{L5}	$\cong$	$\lambda_{L1}/9$			

By knowing the quarter wave optical thickness of the authentic security feature and the above ratios, it is possible to calculate the wavelengths of maximum reflectance (λ_{max}) and the wavelengths of minimum reflectance (λ_{min}) of the security feature (*e.g.*, of the design $M_1DM_2DM_1$). Further, by measuring the reflectance (or transmittance) spectrum of the item to be tested, one can determine the measured values for λ_{max} and λ_{min}. Then by comparing the measured values of λ_{max} and λ_{min} with the values predicted by the formulae, one can determine the authenticity of security feature 16 located on object 14.

In an alternate method, it is possible to scan the security feature and obtain the shape of its reflectance spectrum and/or its transmittance spectrum. The characteristic shape of the measured spectrum is then compared with the reference spectrum of a known authentic feature in order to determine the authenticity of the security feature.

Referring again to Figure 8, verification system 360 has an optical system 368 which includes a broadband light source 374 that generates light in a range of wavelengths, such as from about 350 nm to about 1000 nm, to illuminate in a collimated fashion security feature 16 located on object 14. Suitable devices for light source 374 include various light generators such as but not limited to tungsten filaments, quartz halogen lamps, xenon flash lamps, and broadband light emitting diodes (LED).

A first beam 376 is generated by light source 374 which is incident upon object 14 at an incident angle θ_{1a}. The light source 374 is configured such that incident angle θ_{1a} is in a range from about 0° to about 80° from a normal 50, and preferably from about 5° to about 60°.

The verification system 360 further includes an analyzing system 370 having a similar form to that of analyzing system 20. As such, analyzing system 370 includes a

detector 390 and a data analyzing device 392. Detector 390 preferably has the form of a miniature spectrophotometer, however, detector 390 may also be a spectrograph, that are known by one skilled in the art. The detector 390 is used to measure the magnitude of the reflectance as a function of wavelength for the security feature being analyzed. The detector 390 is configured to receive a light beam 378 reflected at a reflection angle θ_{2a} which is preferably similar in magnitude to incident angle θ_{1a}.

During operation of verification system 360, detector 390 measures the reflectance from security feature 16 on object 14 over a range of wavelengths and combines the reflectance data at each wavelength to generate a spectral curve. Data analyzing device 392 analyzes the spectral curve or shape generated by detector 390 to verify authenticity of security feature 16. Software is used to compare the spectral curve measured from the security feature of an item with a reference spectra stored in a database. If the features of the measured spectra substantially coincide with the features of reference spectra, then the tested item is indicated as genuine.

Another configuration for verification system 360 can utilize a high-precision spectrophotometer or spectrograph and a light source to gather the reflectance spectrum over a range of wavelengths. The reflectance spectrum would be analyzed and the resultant λ_{max} and λ_{min} calculated. The values for λ_{max} and λ_{min} are compared to the expected values in order to determine the authenticity of object 14 and security feature 16.

Referring now to Figure 9, another alternate embodiment of a verification system 410 is depicted. The majority of the feature described with reference to Figure 1 also apply to verification system 410. For example, verification system 410 includes an optical system 418 which includes two light sources 424a and 424b. A unique feature of verification system 410 is the configuration of analyzing system 420.

Analyzing system 420 includes a detector 440, a data analyzing device 442, and a light collector 446. Light collector 446 has four trapezoidal shaped mirrors 448 arranged to form a hollow horn shaped light pipe. An upper end 450 of light collector 446 connects with detector 440, which preferably has the form of a miniature spectrophotometer or spectrograph in this particular embodiment. A lower end 452 of light collector 446 is open to receive light reflected from security feature 16 on object 14. In this configuration, beams 426a and 426b which are incident upon security feature 16 are reflected into cones of reflected light represented by lines 428a, 428b. The cones of

light are incident upon and gathered by light collector 446 to be transmitted to detector 440.

It can be appreciated that one skilled in the art may identify various other configurations of light collector 446 that are capable of performing the function thereof. For example, in another configuration, light collector 446 is configured from a solid piece of optical material that is capable of transmitting and gathering the incident cones of light reflected from optical security feature 16.

The embodiment of Figure 9 is capable of effectively operating with incident illumination of either a single wavelength or a broadband of wavelengths. For example, if light sources 424a, 424b are monochromatic in nature, then detector 440 may be a simple photodiode or the like. In the event that light sources 424a, 424b are broadband light sources, then detector 440 should be a spectrophotometer or spectrograph.

Although verification system 410 is shown to use reflectance data to verify the authenticity of object 14 and security feature 16, one skilled in the art may appreciate that verification system 410 may operate using a transmittance system.

Referring now to Figure 10, another alternate embodiment of a verification system 460 is depicted. The majority of the feature described with reference to verification system 10 also apply to verification system 460. Verification system 460 includes a plurality of verification stations 472a-472n that are laid out longitudinally along the length of transport staging apparatus 12, and more specifically a track 463 thereof. Each station 472a-472n is made from a combination of a light source 474a-474n and a detector 490a-490n of analyzing system 470. Each verification station 472a-472n, therefore, generates a light beam 476a-476n, receives a reflected or transmitted light beam 478a-478n, and transmits data representative of the reflected or transmitted light beam 478a-478n to a data analyzing device.

The configuration of verification system 460 allows for a simple optical alignment of sources 474a-474n and detectors 490a-490n. Additionally, since each station 472a-472n is very simple, reliability may be added in redundancy, through adding more stations 472a-472n than are required to verify the authenticity of object 14. As such, if a few of stations 472a-472n stop functioning, verification system 460 may continue to operate while the failed stations are replaced. This is possible since accurate authenticity verification is possible with the remaining stations. In addition to allowing for redundancy, the speed of verification system 460 is only limited by the rate that object 14 passes under detectors 490a-490n and the rate of data processing.

As depicted, each light source 474a-474n generates a respective light beam 476a-476n having a narrow range of wavelengths of electromagnetic radiation. Each light beam 476a-476n may be incident upon security feature 16 of object 14 at different or similar angular orientations with respect to the angular orientation of the other light beams 476a-476n. Additionally, the wavelength of each light beam 476a-476n may be different or the same as subsequent or preceding light beams 476a-476n. For example, one light beam 476a may have a wavelength in the red region and be incident upon object 14 at a high angle, while another light beam 476b may have a wavelength in the blue region and be incident upon object 14 at a low angle.

One configuration for each of light sources 474a-474n is a light emitting diode (LED) coupled to the end of an optical fiber. Various other configurations of light sources 474a-474n are applicable and known to one skilled in the art.

Verification system 460 further includes an analyzing system 470 having a plurality of detectors 490a-490n positioned along a track 463. Each detector 490a-490n is located opposite to an associated light source 474a-474n, whether on the same side of object 14 or an opposing side of object 14 as depicted by light source 474n and detector 490n. Each detector 490a-490n receives a portion of light beams 476a-476n that is reflected from, or alternatively transmitted through, security feature 16. Each detector 490a-490n may take the form of any of the detectors discussed previously.

The data analyzing device (not shown) of analyzing system 470 combines the information from each station 472a-472n, and specifically from each detector 490a-490n, based on the reflected (or transmitted) light, to identify specific spectral characteristics of security feature 16. Figure 11 is a graphical representation of various reflectivity intensities measured by detectors 490a-490c as a function of time (labeled as detectors A, B and C in the graph). The data analyzing device compares the measured spectral characteristics with stored data of the authentic security feature to thereby verify the authenticity of security feature 16 and object 14. As such, the data analyzing device can take the same form as the data analyzing devices discussed previously.

In operation, object 14, for example currency, passes each station 472a-472n. The light beams 476a-476n are incident upon object 14 at various incident angles, such as two or more different angular orientations, such that the reflected (or transmitted) light is incident upon detectors 490a-490n. Detectors 490a-490n gather data representative of the reflectance (or transmittance) value at each station 472a-472n. Hence, a variety of reflectance and/or transmittance values are measured along the length of track 463. For

instance, station 472a may have an 850 nm light source 474a and a detector 490a arranged at a high angle, thereby giving one reflectance value. The next station 472b may have another 850 nm light source 474b and a detector 490b that is mounted at a low angle that gives a different reflectance value. If the reflectance of security feature 16 measured at 850 nm varies with angle, the comparison of reflectance values between these two different stations 472a, 472b would indicate this difference in 850 nm reflectance.

Additionally, or alternatively, other stations 472c-472n may have light sources, with paired detectors, that emit other wavelengths of electromagnetic radiation such as at 540 nm (green). The stations 472c-472n can be established with light sources 474c-474n emitting a variety of different wavelengths, with light sources 474c-474n and detectors 490c-490n being arrayed at a variety of different angles. In this configuration, the data received from a number of stations 472a-472n may be added together until there are enough combinations of angles and wavelengths that the security feature 16 can be uniquely identified.

The operation of verification system 460 is time dependent, since the optical interference device forming security feature 16 to be analyzed is located at different stations 472a-472n at different times. Therefore, the signals from each of stations 472a-472n may be aligned and later compared. A number of different methods can be employed to re-align the time-dependent signals. One method of accomplishing this is by setting the speed at which object 14 passes by each station 472a-472n, and inserting a time delay on the signals generated by each station 472a-472n so that the signals reach the data analyzing device at essentially the same time, thereby allowing direct comparison of the signals.

Different configurations of detectors can be employed in verification system 460. As shown in Figure 10, discrete detectors are configured along the line of sample motion. Alternatively, one or more linear detector arrays can be mounted at one or more angles along the direction of travel. In still another configuration, two-dimensional detector arrays may be used to provide the reflectance (or transmittance) values as a function of both angle and downstream position.

The structure and method described with respect to verification system 460 has the advantage of eliminating the need to switch light sources 474a-474n "on" and "off" to achieve different incident angles of light and different wavelengths of light.

Referring now to Figure 12, another embodiment of a verification system 510 is depicted. The majority of the feature described with reference to verification system 10 also apply to verification system 510. Verification system 510 has an optical system 518 and an analyzing system 520. Optical system 518 includes two collimated broad-band light sources 524a, 524b that generate two beams of light 526a, 526b. Each source 524a, 524b may include an optical fiber 546a, 546b having a broad-band light source 524a, 524b coupled at a first end 548a, 548b, while a collimating lens 550a, 550b, such as a GRIN lens, is coupled to a second end 552a, 552b. Numerous types of light sources 524a, 524b and collimating lens 550a, 550b are known by one skilled in the art.

Optically communicating with light beams 526a, 526b is analyzing system 520. Analyzing system 520 includes a diffuser 554, and an image recording device such as a camera 556. Diffuser 554 is located in close proximity to object 14 and diffuses the reflected light from security feature 16. Reflected light from security feature 16 will spread out over a range of reflected angles with various wavelengths of electromagnetic radiation or colors selectively going in certain directions due to the characteristics of the optical interference device forming security feature 16. As such, diffuser 554 acts as a rear projection screen, that displays different colors across its surface to thereby form a color spectral pattern as the light back scatters off the surface thereof.

Additionally, diffuser 554 redirects light toward camera 556. Diffuser 554 is selected to balance the amount of light transmitted to camera 556 with respect to the light that is backscattered. A diffuser 554 that scatters relatively more light loses light with absorption, while a diffuser 554 that scatters very little light would allow the observable colors to pass straight through and not reach the camera lens 558.

Diffuser 554 is preferably a planar ground glass diffuser, such as shown in the embodiment of Figure 12. Various other types of diffusers are appropriate, however, such as by way of example and not limitation, a domed diffuser. Such a domed diffuser 554' is depicted in the alternate configuration of a verification system 510' illustrated in Figure 13, which includes similar components as system 510. The domed diffuser 554' has the advantage of providing an even brightness across the surface thereof. The domed diffuser may have the form of a hemisphere, a complete sphere, any portion of a sphere, a portion of an ovular body, or the like. The term "domed" as used herein refers to various curved or curvilinear shapes that have a 3-dimensional or 2-dimensional structure.

Viewing the back scatter of light incident upon diffuser 554 is camera 556, having the form of a color camera, however, various other image recording devices are appropriate. For example, the color camera in analyzing system 520 could be replaced with an infrared camera, or a detector array such as a CCD, linear diode array, or two-dimensional diode array.

The camera 556 is focused on the surface of diffuser 554 to image the pattern of wavelengths or colors generated thereon. The wavelength channels imaged by camera 556 are transmitted to a data analyzing device 542, such as a computer, that has a stored wavelength and position pattern of an authentic security feature 16. Data analyzing device 542 processes the data received by camera 556, by way of recognition algorithms to determine if different wavelengths or colors are reflected in the same way as an authentic security feature 16. The determination may utilize either solely or in combination, the wavelength or color images, the pattern of the images, and the intensity of each color or wavelength. Additionally, since broad-band light sources 524a, 524b generate white spots the color pattern generated by diffuser 554, data analyzing device 542 may compare the location and number of white spots generated by a test object 14 with the number of white spots generated by an authentic object 14 and security feature 16.

Advantages of verification system 510 are that the hardware thereof is very easy to assemble, and tolerance errors are easily calibrated out by data analyzing device 542 through comparing the view image to a sample that reflects in an expected manner.

Referring now to Figure 14, another alternate embodiment of a verification system 560 is depicted. The majority of the features described with reference to verification system 110 also apply to verification system 560. Verification system 560 includes an optical system 568 and an analyzing system 570, each of which are partially depicted. Optical system 568 includes a plurality of light sources 574a-574n, which can be broadband light sources (*e.g.*, white light sources) or narrowband light sources producing discrete wavelengths of electromagnetic radiation (*e.g.*, light emitting diodes) that are arranged in a two-dimensional (2-D) array 572. Similarly, a plurality of detectors 590a-590n, such as spectrophotometers and/or spectrographs, are arranged on the same array 572 at different locations while being in close proximity to light sources 574a-574n. The other portions of both optical system 568 and analyzing system 570 are similar to those previously described and to be further described herein.

In operation, 2-D array 572 is placed in position facing the object with the center of array 572 substantially, directly opposite the security feature 16. The array 572 is preferably planar, however various other configurations of array 572 are possible, such as by way of example and not limitation, hemispherical shape, dome shape, or the like. The array 572 is connected to a control system (not shown) that activates one or more of light sources 574a-574n and receives data from one or more of source 590a-590n at a given time.

Various methods of operating verification system 560 are discussed as follows. The discussion herein is provided for explanatory purposes and shall not be considered as excluding the applicability of the present invention from different modes of operation, different wavelengths of electromagnetic radiation, or different configurations of verification system 560.

In one example, light sources 574a-574n emit white light, while detectors 590a-590n give RGB (red, green, and blue) signal outputs to data analyzing device 592 that are proportional to the red, green, and blue intensities of the light reaching detectors 590a-590n. When, for example, one of light sources 574a-574n located substantially at the center of array 572 is turned on, detectors 590a-590n record the RGB signals as a function of position on array 572 (and hence angle from the sample). The signals from each detector 590a-590n are then integrated by data analyzing device 592 into a reflectance map which is characteristic of the sample. For example, object 14 incorporating an optical interference device such as optically variable pigment as described in Phillips '812 has a different reflectance map than that obtained from other types of pigment. In the example of security feature 16 being made using magenta-to-green optically variable pigment, turning on the center light source of light source 574a-574n in array 572 causes detectors 590a-590n adjacent to the activated light source 574a-574n to detect the near-normal reflected color of magenta. On the reflectance map created from the detector signals, each detector 590a-590n positioned radiating outward from one light source 574a-574n would detect colors progressing from magenta, through gold and finally to green at one of the detectors 590a-590n positioned around the perimeter of array 572 where the angle is furthest away from the surface normal. In this example, the data analyzing device 592 provides not only the color values from detectors 590a-590n but also the intensity measured by each detector.

In this example wherein security feature 16 is produced using flakes of optical interference pigment and those flakes are primarily aligned with the plane of object 14,

the intensity of the detected signal tends to decrease radially from the position of the light source due to the fact that few flakes are positioned at high angles of tilt.

In the event that one of light sources 574a-574n at the perimeter is activated rather than one of light source 574a-574n at the center, the most intense signal will again be detected at those positions at which the angle of incidence is closest to the angle of reflection, but in this alternate example, this will not be for the detectors near the source. If the light used is the top, center position, then the greatest intensity will be achieved at the bottom center position. Given the same magenta-to-green optically variable pigment sample, the bottom center detector would detect a green color with high intensity given a detection angle of about 45 degrees while the detectors near the light source would see a magenta color with lower intensity. Therefore, by electrically switching different light sources 574a-574n in array 572, the detector array would obtain intensity and color signals which produce a sequence of maps which are both individually and collectively characteristic of the specific optical interference device being interrogated.

It should be appreciated that other combinations of light sources 574a-574n and detector types could be used in array 572. For example, the white light sources could be replaced with light emitting diodes (LEDs) that emit a narrower range of wavelengths (or selectable wavelengths). If these LEDs are mounted alongside broadband detectors (such as silicon-based detectors), then one would obtain a series of maps giving intensity data as a function of wavelength, light source position, and detector position. By switching "on" and "off" different LEDs, one would obtain a series of maps which again would be characteristic of the optical interference device of security feature 16. This configuration is advantageous in that the detectors and LED light sources are less expensive to utilize.

Referring now to Figure 15, another embodiment of a verification system 610 is depicted. The majority of the features described with reference to verification system 10 also apply to verification system 610. Verification system 610 includes an optical system 618 and an analyzing system 620. Verification system 610 allows numerous beams of light to be incident upon object 14 and security feature 16 at varying angles, while analyzing system 620 receives the reflected or transmitted light at different discrete angles, thereby allowing a determination of authenticity of security feature 16 of object 14.

As depicted in Figure 15, verification system 610 is configured to utilize the reflectance characteristics to verify the authenticity of object 14 by security feature 16, although one skilled in the art may identify various other configurations that utilize

transmittance characteristics either solely or in combination with the reflectance characteristics to verify the authenticity of object 14. Optical system 618 has a plurality of light sources 624a-624n each coupled to a plurality of light transmitting optical fibers 622a-622n. Each light source 624a-624n coupled to optical fibers 622a-622n either generates a discrete wavelength of electromagnetic radiation, such as a monochromatic beam generated by a laser or LED, or alternatively a broadband of electromagnetic radiation, such as from a white light source. The ends of optical fibers 622a-622n distal from light sources 624a-624n are attached together to form an optical fiber bundle 630, thereby allowing light sources 624a-624n to be small, robust, and durable, while providing for easier installation and use. The arrangement of the ends of optical fibers 622a-622n must be performed carefully to limit the effect of coupling of light at high cone angles during operation of verification system 610.

One or more of the distal ends of optical fibers 622a-622n may include a focusing or narrowing lens 632a-632n, such as a GRIN lens or a micro-ball lens, to reduce the cone angle of the light exiting from optical fibers 622a-622n, from a typical cone angle of about 35 degrees corresponding to a numerical aperture of 0.3 to a cone angle of about 12 degrees corresponding to a numerical aperture of 0.1. As such, light exiting from the distal end of each optical fiber 622a-622n will be incident upon security feature 16 at varying angular orientations.

Optically communicating with a plurality of beams 628a-628n reflected from the surface of or transmitted through security feature 16 are one or more detectors 640a-640n. Each detector 640a-640n may take the form of a spectrophotometer or spectrograph, or a number of detectors having filters that allow passage of certain regions of the spectrum. Detectors 640a-640n are located in close proximity to security feature 16 to limit the effects of optical coupling at high angles from optical fibers 622a-622n on the periphery of optical bundle 630. Detectors 640a-640n collect the reflected light as each light source 624a-624n is turned "on" and "off" in a timed sequence. By so doing, detectors 640a-640n gather the intensities of reflected and/or transmitted light incident upon each detector 640a-640n, for varying angularly incident cones of light have various wavelengths or colors within the predetermined timed sequence. The reflectance (or transmittance) data is relayed to data analyzing device 642 that manipulates the data to determine the pattern of light intensities, wavelengths (or colors) and angles. The pattern is compared to the stored pattern characteristic of an authentic security feature to verify the authenticity of object 14.

As depicted in Figure 15, detectors 640a-640n may be coupled to a plurality of light receiving optical fibers 644a-644n. As such, light reflected from or transmitted by security feature 16 travels towards at the distal ends of optical fibers 644a-644n along multiple optical paths. Light is transmitted along optical fibers 644a-644n to respective detectors 640a-640n for measurement and conversion to electronic signals which are sent on to data analyzing device 642 for manipulation.

In an alternate configuration of a verification system 710 shown in Figure 16, which has similar components as system 610, optical fibers 622a-622n are coupled with light sources 624a-624n, and optical fibers 644a-644n are coupled to detectors 640a-640n. The optical fibers are intertwined such that distal ends of optical fibers 622a-622n and 644a-644n can be bound together within the same optical fiber bundle 630. By so doing, only a single optical bundle 630 is placed in close proximity to object 14 and security feature 16, limiting the space required and reducing the complexity of verification system 710.

Generally, the present invention may be embodied in various structures that perform various functions, such as, but not limited to (i) means for directing a first light beam at a first incident angle and a second light beam at a second incident angle toward an object to be authenticated; (ii) means for positioning an object such that the first and second light beams are incident on a portion of the object where an optical interference security feature should be located; and (iii) means for analyzing one or more optical characteristics of the first light beam directed from the object along a first optical path and the second light beam directed from the object along a second optical path to verify the authenticity of the object. For example, various structures capable of performing the function of directing light beams at different incident angles are described for the optical systems of the preceding embodiments of the present invention. Illustrative structures performing the light directing function include one or more narrowband or broadband light sources that generate one or more beams of light to be incident upon an object, such as shown in the embodiments of Figures 1, 3, 5, and 9. Another illustrative structure performing the light directing function is depicted in Figures 4 and 6, where one light source generates a single light beam that is split into two light beams by way of a beam splitter and a mirror. Yet another structure that is capable of performing the light directing function is depicted in Figure 7, where a single light beam is incident upon a rotating mirror that reflects the light beam at varying incident angles toward an object. Other structures performing the light directing function are depicted in Figures 12-13 and

15-16, where multiple light sources are coupled to the ends of optical fibers. Still other structures that are capable of performing the light directing function are depicted in Figure 10, where a number of light sources are positioned along a row, and in Figure 14, where a number of light sources are spaced apart in an array.

Various structures capable of performing the function of positioning an object such that the light beams are incident on a portion of the object where an optical interference security feature should be located are described for the preceding embodiments of the invention. For example, the transport staging apparatus described for the above embodiments performs the function of positioning an object. As discussed above, numerous configurations for performing the desired transporting and positioning functions can be employed, such as a belt or conveyor that carries and/or holds an object in the required orientation, moving the object in a linear fashion past the optical system. In addition, a staging apparatus can provide for stationary positioning of an object in a verification system of the invention.

There are various structures capable of performing the function of analyzing one or more optical characteristics of the light beams directed from the object to verify the authenticity of an object. For example, the analyzing systems described for the preceding embodiments of the present invention perform the analyzing function. More specifically, these analyzing systems can include at least one spectrophotometer or spectrograph, and may include multiple detectors and detector arrays. The analyzing systems also include a data analyzing device which cooperates with one or more detectors to analyze the spectral shift or spectral curve of the light beams reflected or transmitted at various angles. It can be appreciated that there are various other structures that will perform the analyzing function which are known by those skilled in the art.

It should be understood that each of the preceding embodiments of the present invention may utilize a portion of another embodiment, and should not be considered as limiting the general principals discussed herein. For example, each of the embodiments, and other applicable adaptations and configurations may utilize the beneficial effects of analyzing transmitted rather than reflected light from security feature 16 and object 14. Furthermore, each of the light sources described herein may be comprised of a single or multiple source of narrowband and/or broadband light which is transmitted through the air or some other gaseous medium, through an optical waveguide such as an optical fiber, or through a vacuum. Additionally, each verification system may utilize a beam splitter and mirror configuration, or fiber optics, such that a light beam is split into two or more

separate beams that are reflected and then received by multiple detectors or a single array detector, or recombined into a single beam received by a single detector. Finally, each light source may generate a continuous light beam or alternating light beam that is incident upon the security feature and object.

In addition, it should be understood that various embodiments discussed herein can be configured and miniaturized through existing technologies to operate as hand-held units, and thus would not require a transport staging apparatus.

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the forgoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. A system for verifying the authenticity of an object, comprising:

(a) means for directing a first light beam at a first incident angle and a second light beam at a second incident angle toward an object to be authenticated;

(b) means for positioning the object such that the first and second light beams are incident on a portion of the object where an optical interference security feature should be located; and

(c) means for analyzing one or more optical characteristics of the first light beam directed from the object along a first optical path and the second light beam directed from the object along a second optical path to verify the authenticity of the object.

2. The system of claim 1, wherein the first light beam and the second light beam are from one or more monochromatic light sources.

3. The system of claim 2, wherein the one or more light sources are laser devices.

4. The system of claim 1, wherein first light beam and the second light beam are from one or more broadband light sources.

5. The system of claim 1, wherein the positioning means comprises a transport staging apparatus that is capable of passing a plurality of objects past the first light beam and the second light beam.

6. The system of claim 1, wherein the analyzing means comprises at least one optical detector operatively connected to a data analyzing device, the optical detector being configured to receive the first light beam along the first optical path and the second light beam along the second optical path from the object.

7. The system of claim 6, wherein one or both of the first and second light beams are reflected from the object.

8. The system of claim 6, wherein one or both of the first and second light beams are transmitted through the object.

9. The system of claim 6, wherein the data analyzing device and the optical detector are configured to use the spectral shape of the first light beam and the second light beam directed along the first optical path and the second optical path respectfully to verify the authenticity of the object.

10. The system of claim 6, wherein the data analyzing device and the optical detector are configured to use the spectral shift of the first light beam and the second light

beam directed along the first optical path and the second optical path respectfully to verify the authenticity of the object.

11. The system of claim 6, wherein the data analyzing device and the optical detector are configured to use the dispersion pattern of the first light beam and the second light beam directed along the first optical path and the second optical path respectfully to verify the authenticity of the object.

12. The system of claim 6, wherein the at least one optical detector is a spectrophotometer.

13. The system of claim 6, wherein the at least one optical detector is a spectrograph.

14. A system for verifying the authenticity of an object, comprising:

(a) a light source capable of generating a light beam;

(b) a beam splitter in optical communication with the light source and configured to split the light beam into a first light beam and a second light beam, the second light beam being reflected from the beam splitter while the first light beam is transmitted toward an object at a first incident angle;

(c) a mirror configured to reflect the second light beam toward the object at a second incident angle that is different from the first incident angle;

(d) a first optical detector configured to receive the first light beam directed from the object along a first optical path;

(e) a second optical detector configured to receive the second light beam directed from the object along a second optical path; and

(f) a data analyzing device operatively connected to the first and second optical detectors and adapted to analyze one or more signals from the first optical detector and the second optical detector to determine the spectral shift of the first and second light beams directed along the first and second optical paths from the object to verify the authenticity of the object.

15. The system of claim 14, wherein the light source is capable of generating a monochromatic light beam.

16. The system of claim 14, wherein the light source is capable of generating a broadband light beam.

17. The system of claim 14, wherein at least one of the first and second light sources is a laser device.

18. The system of claim 14, further comprising a transport staging apparatus configured to position the object such that the first and second light beams are incident on a portion of the object where an optical interference security feature should be located.

19. The system of claim 18, wherein the transport staging apparatus is capable of passing a plurality of objects past the first and second light sources.

20. The system of claim 14, wherein the first and second optical detectors are selected from the group consisting of spectrophotometers, spectrographs, and combinations thereof.

21. The system of claim 14, wherein the beam splitter is a beam splitter selected from the group consisting of a polarizing beam splitter, a cubic beam splitter, a partial reflector, and combinations thereof.

22. A system for verifying the authenticity of an object, comprising:

(a) a first light source configured to direct a first light beam toward an object at a first incident angle, and a second light source configured to direct a second light beam toward the object at a second incident angle that is different from the first incident angle;

(b) a first optical detector configured to receive the first light beam directed from the object along a first optical path;

(c) a second optical detector configured to receive the second light beam directed from the object along a second optical path; and

(d) a data analyzing device operatively connected to the first and second optical detectors and adapted to analyze one or more signals from the first and second optical detectors to determine the spectral shift or shape of the first and second light beams directed along the first and second optical paths from the object to verify the authenticity of the object.

23. The system of claim 22, wherein at least one of the first and second light sources is capable of generating a monochromatic light beam.

24. The system of claim 22, wherein at least one of the first and second light sources is a laser device.

25. The system of claim 22, wherein at least one of the first and second light sources is capable of generating a broadband light beam.

26. The system of claim 22, further comprising a transport staging apparatus configured to position the object such that the first and second light beams are incident on a portion of the object where an optical interference security feature should be located.

27. The system of claim 26, wherein the transport staging apparatus is capable of passing a plurality of objects past the first and second light sources.

28. The system of claim 22, wherein the first and second optical detectors are selected from the group consisting of spectrophotometers, spectrographs, and combinations thereof.

29. A system for verifying the authenticity of an object, comprising:

(a) a light source configured to direct an incident light beam toward an object to be authenticated;

(b) an optical detector configured to a receive the light beam directed along a first optical path from the object; and

(c) a data analyzing device operatively connected to the optical detector and adapted to analyze the spectral shape generated by the optical detector to verify the authenticity of the object.

30. The system of claim 29, wherein the light source generates a broadband light beam.

31. The system of claim 29, further comprising a transport staging apparatus configured to position the object such that the incident light beam strikes a portion of the object where an optical interference security feature should be located.

32. The system of claim 31, wherein the transport staging apparatus is capable of passing a plurality of objects past the light source.

33. The system of claim 29, wherein the optical detector is selected from the group consisting of a spectrophotometer, a spectrograph, and combinations thereof.

34. The system of claim 29, wherein the optical detector comprises a linear variable filter mounted to a linear diode array.

35. A system for verifying the authenticity of an object, comprising:

(a) at least one light source configured to direct at least one light beam at a first incident angle toward an object to be authenticated;

(b) a transport staging apparatus adapted to position the object such that the at least one light beam is incident on a portion of the object where an optical interference security feature should be located; and

(c) an analyzing apparatus adapted to analyze the electromagnetic spectrum of diffused light directed from the object to verify the authenticity of the object.

36. The system of claim 35, further comprising an additional light source configured to direct an additional light beam at a second incident angle toward the object to be authenticated.

37. The system of claim 35, wherein the analyzing apparatus comprises a diffuser and at least one image recording device in optical communication with the diffuser.

38. The system of claim 37, wherein the analyzing apparatus further includes a data analyzing device operatively coupled to the image recording device and adapted to analyze the backscatter pattern of light incident upon the diffuser.

39. The system of claim 37, wherein the diffuser comprises a planar diffuser.

40. The system of claim 37, wherein the diffuser comprises a domed diffuser.

41. The system of claim 35, wherein the analyzing apparatus comprises a diffuser and at least one detector array in optical communication with the diffuser.

42. The system of claim 35, wherein the analyzing apparatus is adapted to analyze the color spectrum of diffused light directed from the object.

43. A system for verifying the authenticity of an object, comprising:

(a) at least one light source configured to direct at least one light beam at a first incident angle toward an object to be authenticated;

(b) a light collector adapted to collect the light beam directed from the object along a first optical path; and

(c) an analyzing apparatus operatively connected to the light collector and adapted to analyze the optical characteristics of the light beam directed from the object into the light collector to verify the authenticity of the object.

44. The system of claim 43, further comprising an additional light source configured to direct an additional light beam at a second incident angle toward the object to be authenticated.

45. The system of claim 43, further comprising a transport staging apparatus adapted to position the object such that the light beam is incident on a portion of the object where an optical interference security feature should be located.

46. The system of claim 43, wherein the analyzing apparatus comprises an optical detector and a data analyzing device.

47. The system of claim 43, wherein the light collector has a hollow interior.

48. The system of claim 43, wherein the light collector has a tapered configuration.

49. A system for verifying the authenticity of an object, comprising:

(a) a light source configured to generate a light beam;

(b) an optical scanning device in optical communication with the light source and capable of directing the light beam toward an object at varying incident angles; and

(c) an analyzing apparatus adapted to analyze the optical characteristics of the light beam directed from the object along one or more optical paths to verify the authenticity of the object.

50. The system of claim 49 , wherein the light source generates a monochromatic light beam.

51. The system of claim 49, wherein the light source is a laser device.

52. The system of claim 49, wherein the light source generates a broadband light beam.

53. The system of claim 49, further comprising a lens in optical communication with the optical scanning device and adapted to focus the light beam upon the object, the optical scanning device comprising a rotatable mirror.

54. The system of claim 49, further comprising a transport staging apparatus configured to position the object such that the light beam strikes a portion of the object where an optical interference security feature should be located.

55. The system of claim 49, wherein the analyzing apparatus comprises at least one optical detector and at least one data analyzing device.

56. The system of claim 55, wherein the optical detector is a linear detector array.

57. The system of claim 55, further comprising a timing circuit operatively connected to the optical scanning device and the data analyzing device.

58. A system for verifying the authenticity of an object, comprising:

(a) a plurality of light sources each configured to direct a light beam toward an object; and

(b) an analyzing apparatus comprising a plurality of optical detectors and adapted to analyze the optical characteristics of the light beams reflected from the object at varying reflectance angles to verify the authenticity of the object;

wherein the plurality of light sources and the plurality of optical detectors are located adjacent to each other in an array.

59. The system of claim 58, further comprising a transport staging apparatus configured to position the object such that one or more light beams strike a portion of the object where an optical interference security feature should be located.

60. The system of claim 58, wherein the array is a substantially planar array.

61. The system of claim 58, wherein the array has a domed configuration.

62. The system of claim 58, wherein each of the plurality of light sources generates a discrete wavelength of electromagnetic energy.

63. The system of claim 58, wherein each of the plurality of light sources generates a broad band of wavelengths of electromagnetic energy.

64. The system of claim 58, wherein one or more of the plurality of light sources may be activated or deactivated simultaneously.

65. A system for verifying the authenticity of an object, comprising:

(a) a plurality of verification stations each of which include a light source configured to generate a light beam, and at least one corresponding optical detector;

(b) a transport staging apparatus configured to position an object such that one or more light beams strike a portion of the object where an optical interference security feature should be located; and

(c) an analyzing apparatus adapted to analyze the optical characteristics of the light beams directed from the object to verify the authenticity of the object.

66. The system of claim 65, wherein each light source is configured so that the light beams are incident upon the object at two or more different angular orientations.

67. The system of claim 65, wherein each light source is configured to produce a light beam having a different and discrete wavelength from the other light beams.

68. The system of claim 65, wherein two or more of the plurality of verification stations generates light beams of substantially the same wavelength.

69. A system for verifying the authenticity of an object, comprising:

(a) means for directing a first light beam at a first incident angle and a second light beam at a second incident angle toward an object to be authenticated;

(b) a first mirror configured to reflect a first light beam directed from the object along a first optical path;

(c) a first beam splitter configured to combine the first light beam reflected by the mirror with a second light beam directed from the object along a second optical path; and

(d) an analyzing apparatus adapted to analyze the optical characteristics of the combined first light beam and second light beam to verify the authenticity of the object.

70. The system of claim 69, wherein the light beam directing means includes a first light source that produces the first light beam and a second light source that produces the second light beam.

71. The system of claim 69, wherein the light beam directing means includes a second mirror and a second beam splitter that cooperate with a light source to generate the first light beam and the second light beam.

72. The system of claim 69, further comprising a transport staging apparatus configured to position the object such that the first and second light beams are incident on a portion of the object where an optical interference security feature should be located.

73. A system for verifying the authenticity of an object, comprising:

(a) an optical system comprising:

(i) a plurality of light transmitting optical fibers each having a first end and a second end, the first ends of the optical fibers being coupled together to form a fiber bundle; and

(ii) a plurality of light sources coupled to the second ends of the optical fibers and being configured to generate a plurality of light beams; and

(b) an analyzing apparatus adapted to analyze the optical characteristics of the light beams directed from the object along one or more optical paths to verify the authenticity of the object.

74. The system of claim 73, wherein each light source is configured to generate a light beam having a different wavelength from the other light beams.

75. The system of claim 73, further comprising a transport staging apparatus configured to position an object such that the light beams strike a portion of the object where an optical interference security feature should be located.

76. The system of claim 73, wherein the analyzing apparatus comprises at least one detector and at least one data analyzing device.

77. The system of claim 76, wherein the analyzing apparatus further comprises one or more light receiving optical fibers each of which is coupled to a corresponding detector.

78. The system of claim 77, wherein the light receiving optical fibers coupled to the detectors are interwoven with the light transmitting optical fibers coupled to the light sources.

79. A method for verifying the authenticity of an object, comprising the steps of:

(a) directing a first light beam at a first incident angle and a second light beam at a second incident angle toward an object to be authenticated;

(b) positioning the object such that the first and second light beams are incident on a portion of the object where an optical interference security feature should be located; and

(c) analyzing one or more optical characteristics of the first light beam directed from the object along a first optical path and the second light beam directed from the object along a second optical path to verify the authenticity of the object.

80. The method of claim 79, wherein at least one of the first and second light beams is a monochromatic light beam.

81. The method of claim 79, wherein at least one of the first and second light beams is generated by a laser device.

82. The method of claim 79, wherein at least one of the first and second light beams is a broadband light beam.

83. The method of claim 79, further comprising the step of moving a plurality of objects to be authenticated past the light beams.

84. The method of claim 79, wherein the step of analyzing the optical characteristics comprises comparing a measured spectral shift between the first and second light beams directed from the object at different angular orientations against a reference spectral shift.

85. The method of claim 84, wherein the measured spectral shift occurs at a single wavelength of light.

86. The method of claim 84, wherein the measured spectral shift is verified over a range of wavelengths of electromagnetic radiation.

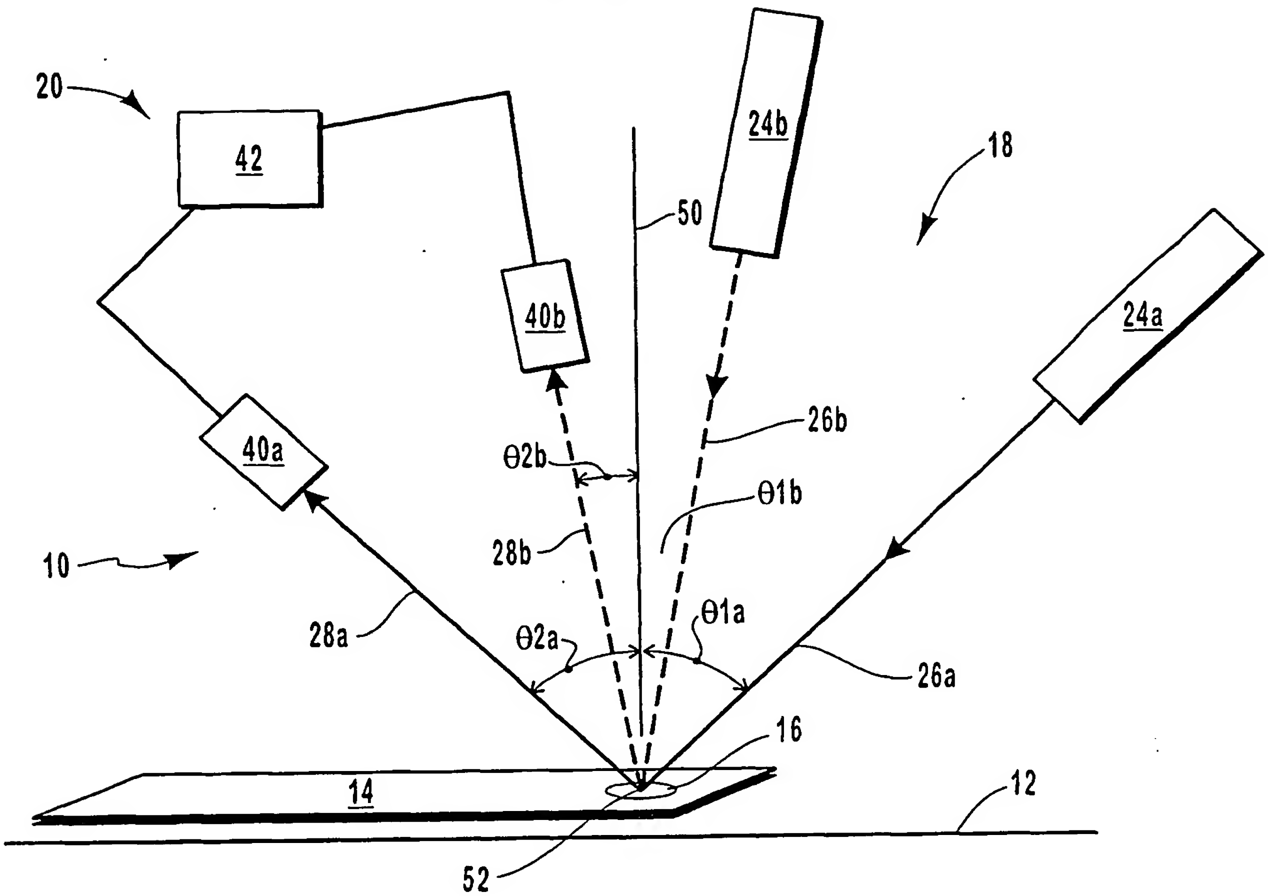
87. The method of claim 84, wherein the measured spectral shift is compared to the reference spectral shift by determining a reflectance intensity of the first and second light beams at different angular orientations which is compared with stored reference reflectance ratios at one or more wavelengths.

88. The method of claim 79, wherein the step of analyzing the optical characteristics comprises comparing the spectral shape of the first and second light beams directed from the object against a reference spectral shape.

89. The method of claim 79, wherein the step of analyzing the optical characteristics comprises analyzing the dispersion pattern of the first and second light beams directed from the object.

90. The method of claim 79, wherein the step of analyzing the optical characteristics comprises the step of analyzing the reflectance characteristics of one or both of the first light beam and the second light beam that is reflected from the object along the first optical path and the second optical path, respectively, to verify the authenticity of the object.

91. The method of claim 79, wherein the step of analyzing the optical characteristics comprises the step of analyzing the transmission characteristics of one or both of the first light beam and the second light beam that is transmitted through the object along the first optical path and the second optical path, respectively, to verify the authenticity of the object.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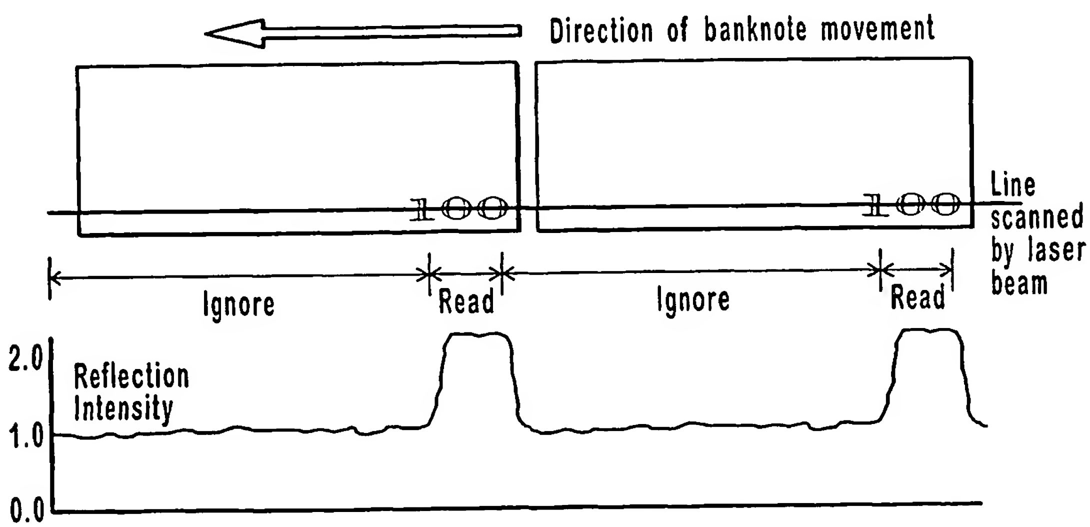
Θ2a
Θ1a
26a
16
14
12
52

FIG. 1


Direction of banknote movement
Line scanned by laser beam
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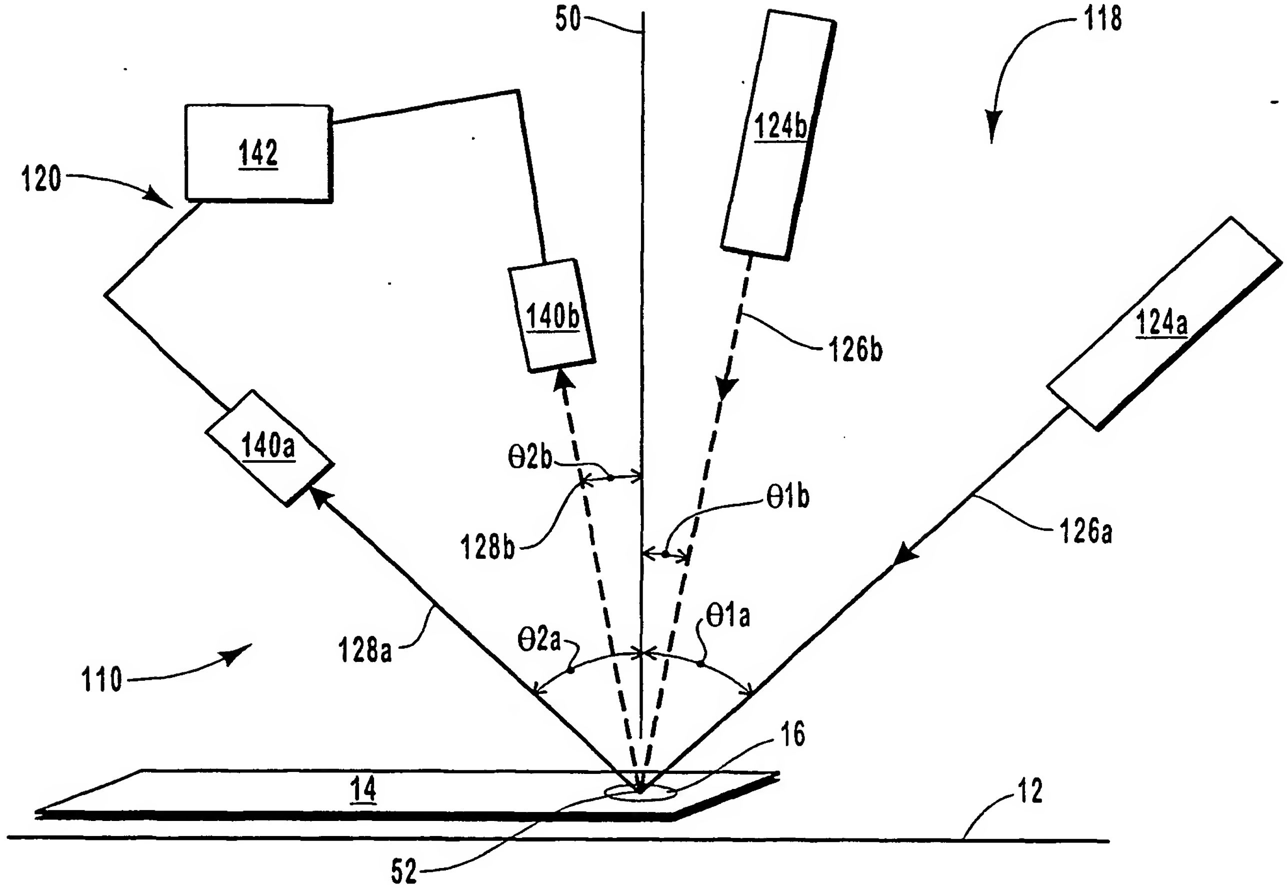
Read
Ignore
Read
2.0
Reflection Intensity
1.0
0.0

FIG. 2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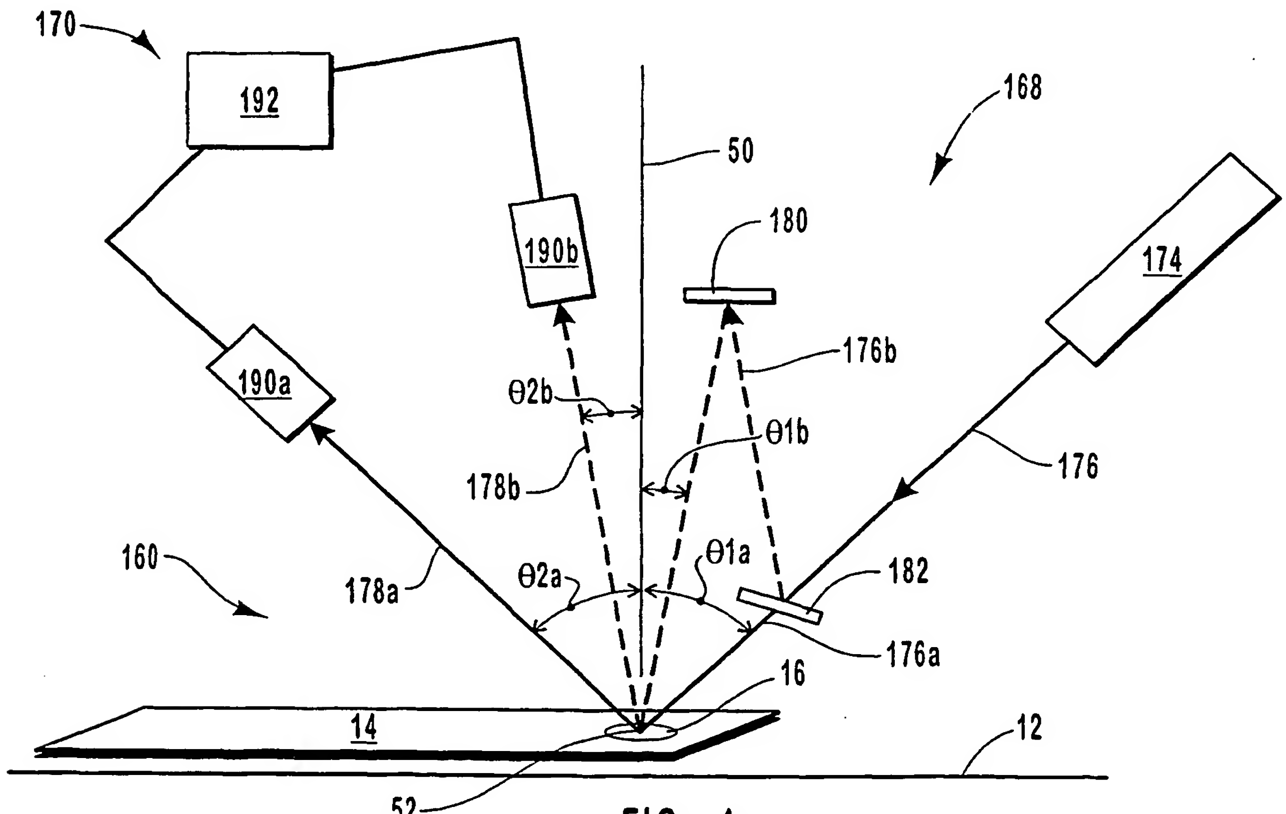
16
14
12
52

FIG. 3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180
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Θ2a
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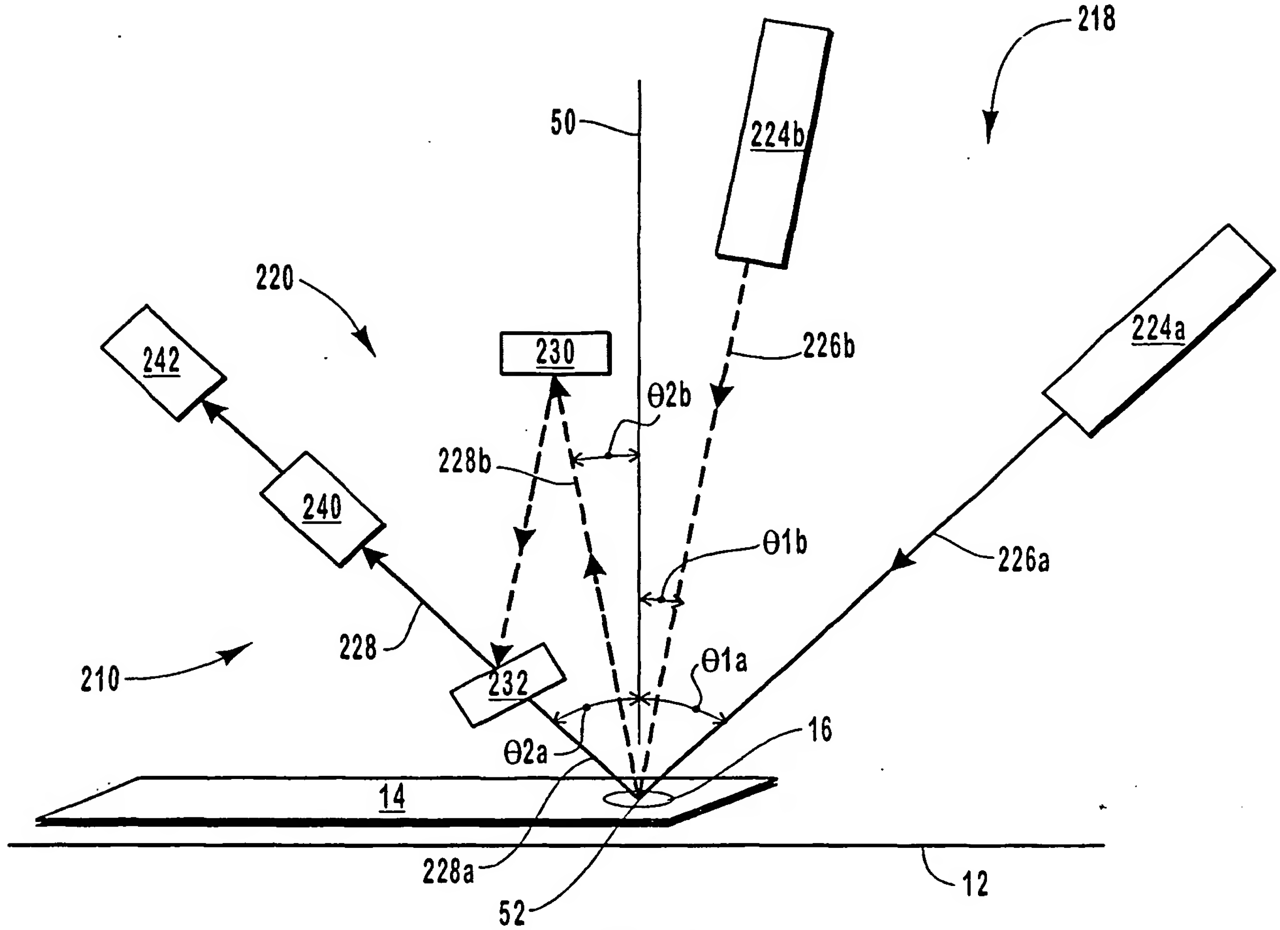
176a
16
14
12
52

FIG. 4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50
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224a
242
230
226b
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θ1a
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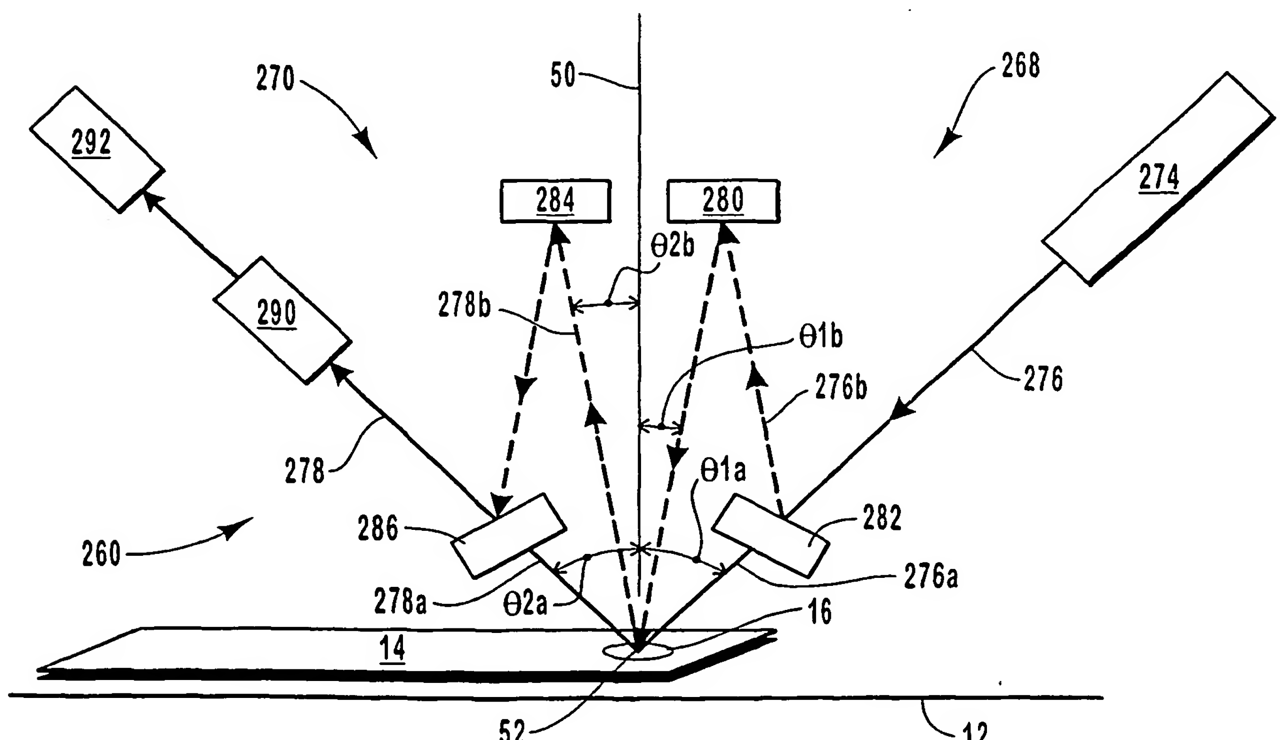
228a
12
52

FIG. 5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268
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274
284
280
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278b
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θ1b
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278
θ1a
286
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260
278a
θ2a
276a
16
14
52
12

FIG. 6

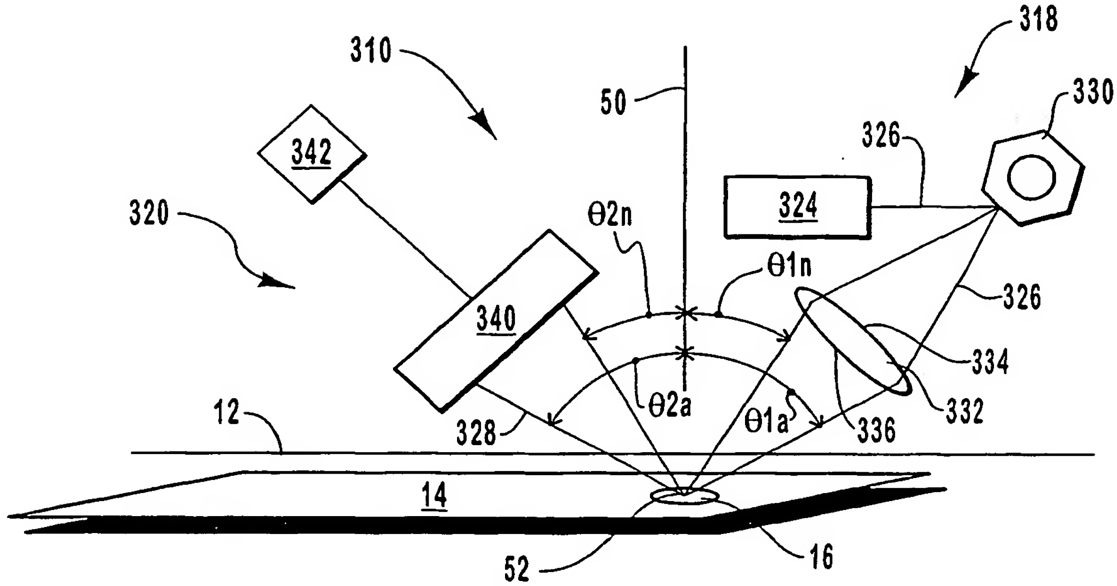
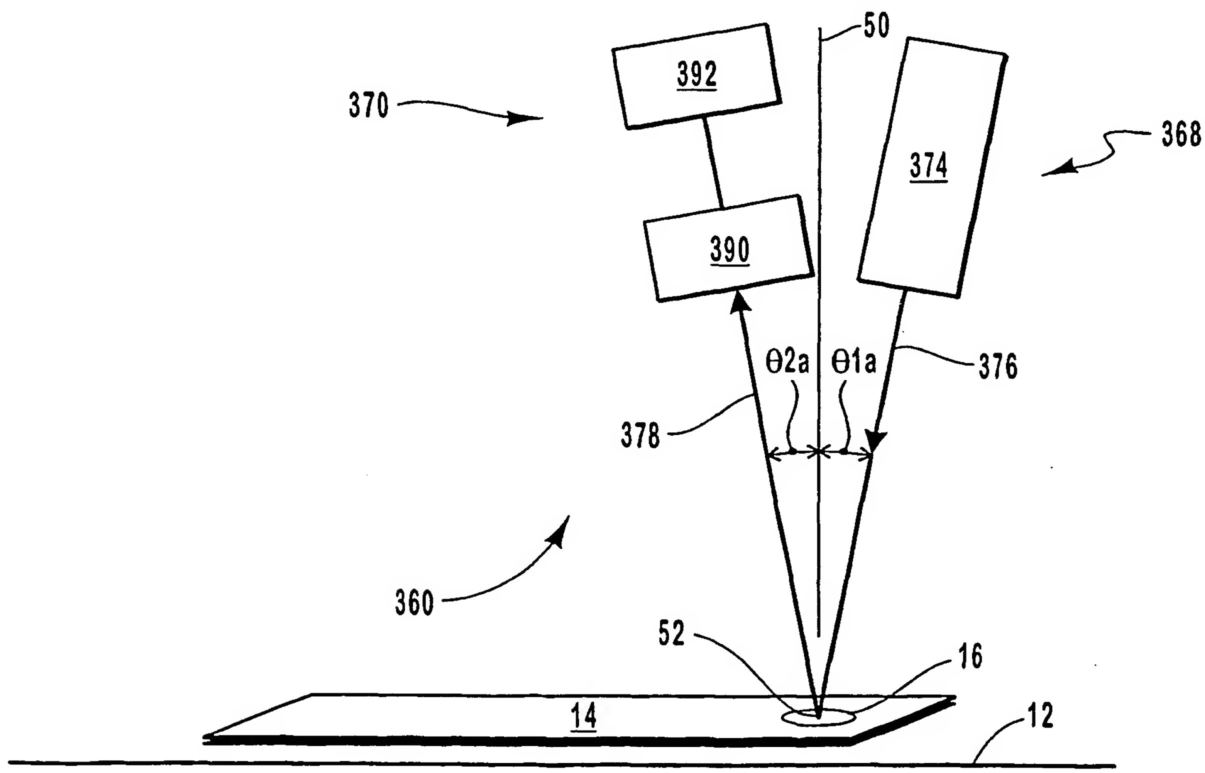

310
318
330
50
326
342
324
320
θ2n
θ1n
326
340
334
332
12
θ2a
θ1a
336
328
14
52
16

FIG. 7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374
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θ2a
θ1a
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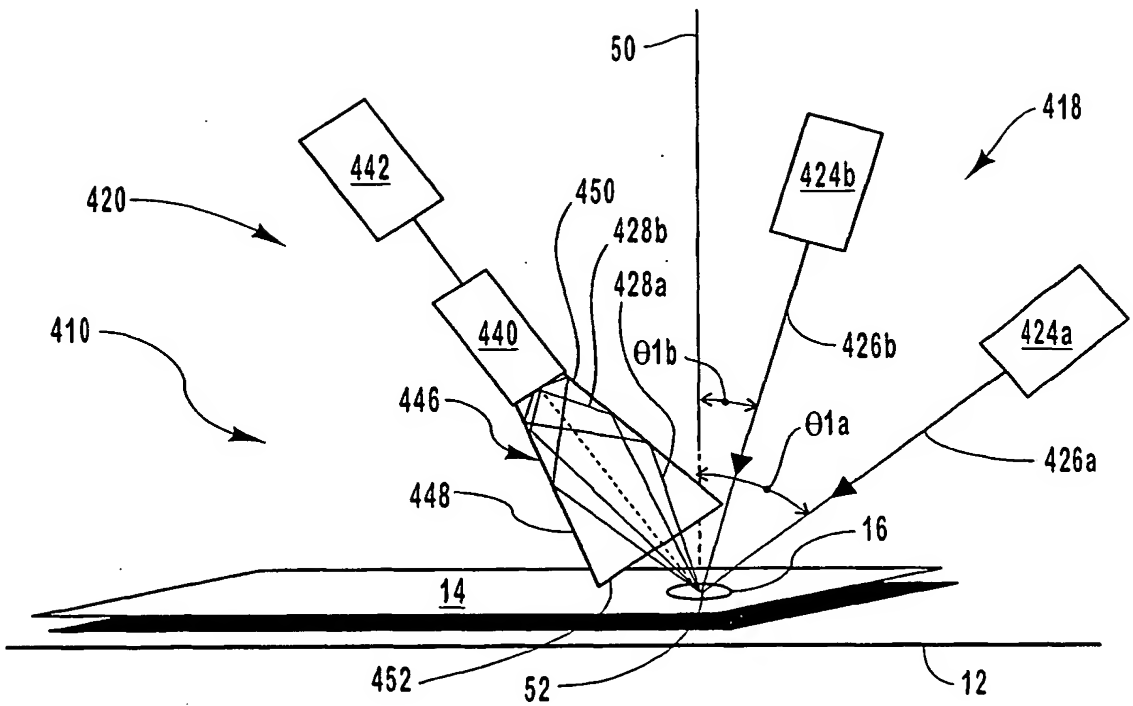
378
360
52
16
14
12

FIG. 8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424b
420
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428b
428a
440
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Θ1b
426b
446
Θ1a
426a
448
16
14
452
52
12

FIG. 9

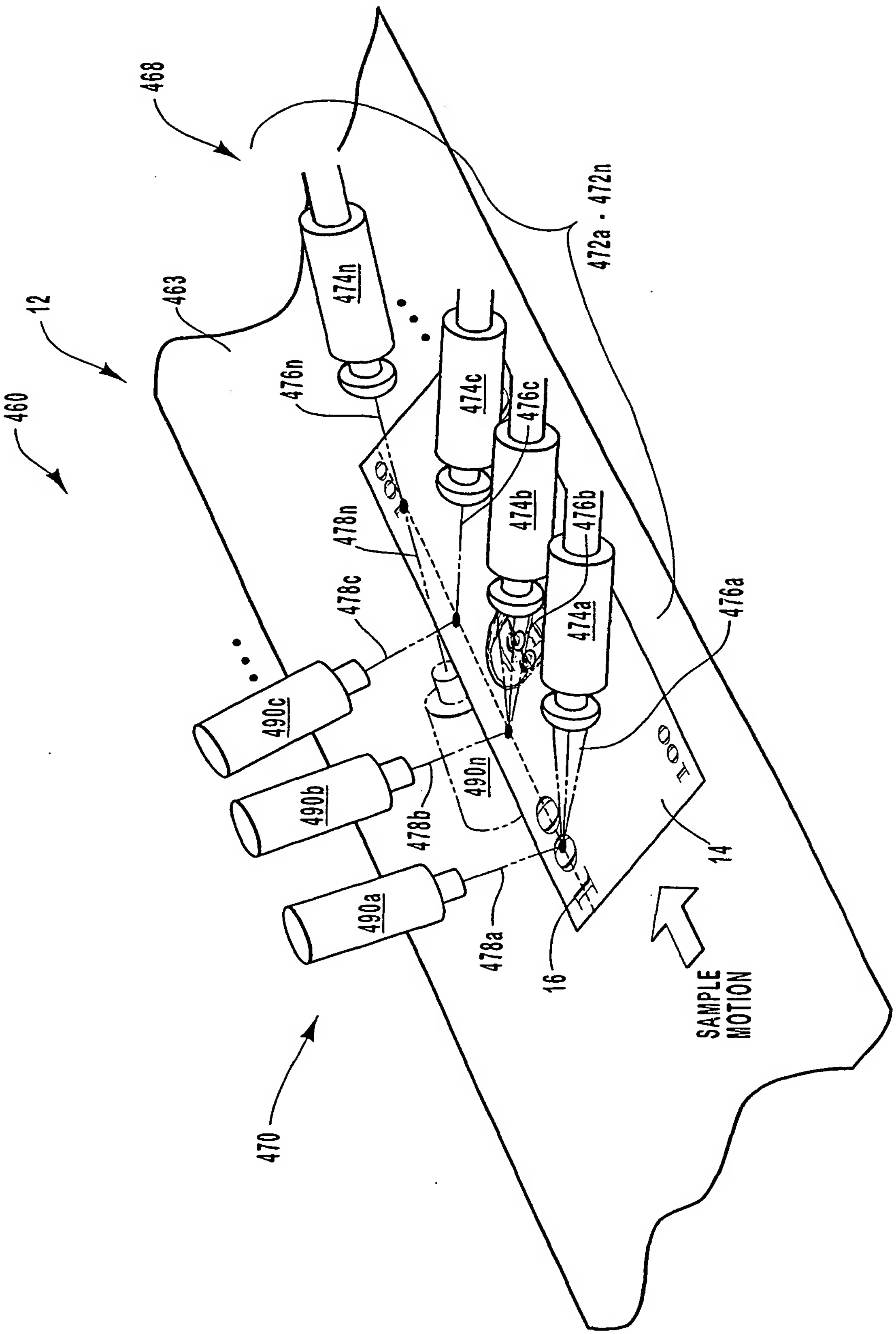

468
463
12
460
474n
472a - 472n
476n
474c
476c
474b
476b
478n
478c
474a
476a
490c
490n
490b
478b
490a
478a
14
16
SAMPLE MOTION
470

FIG. 10

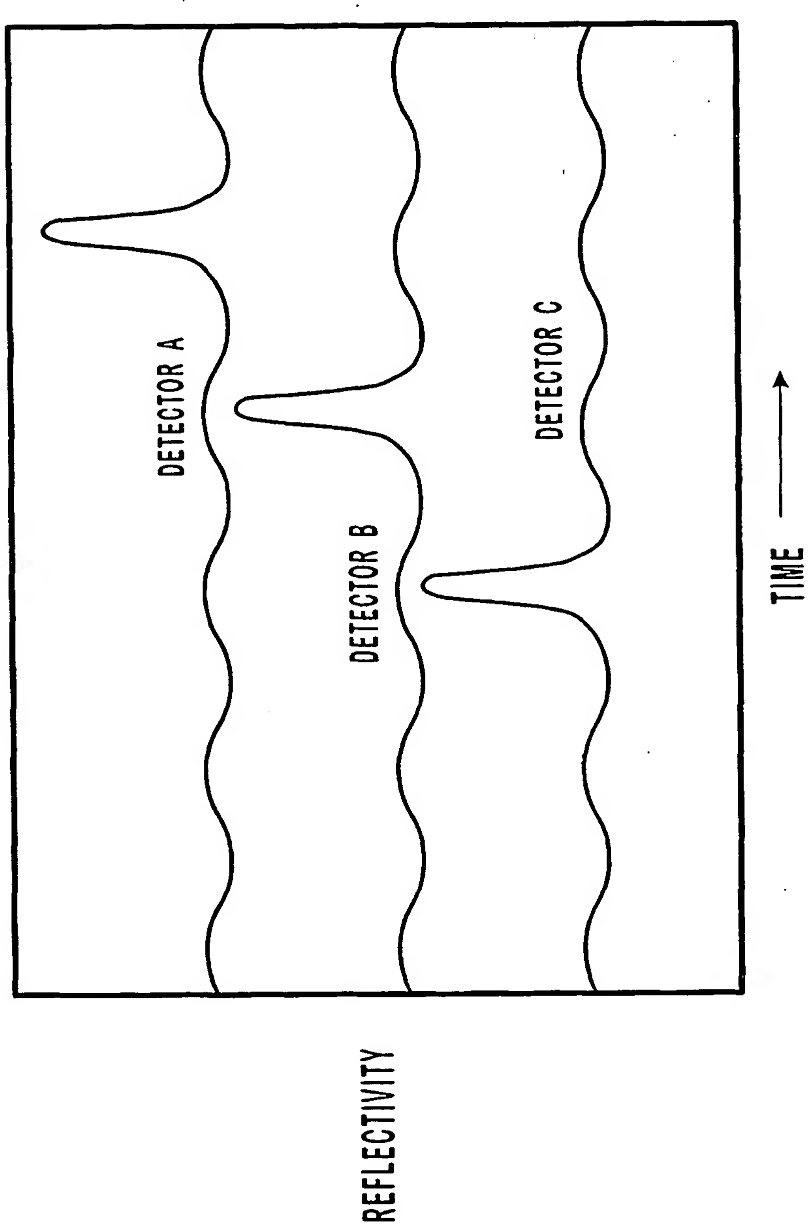
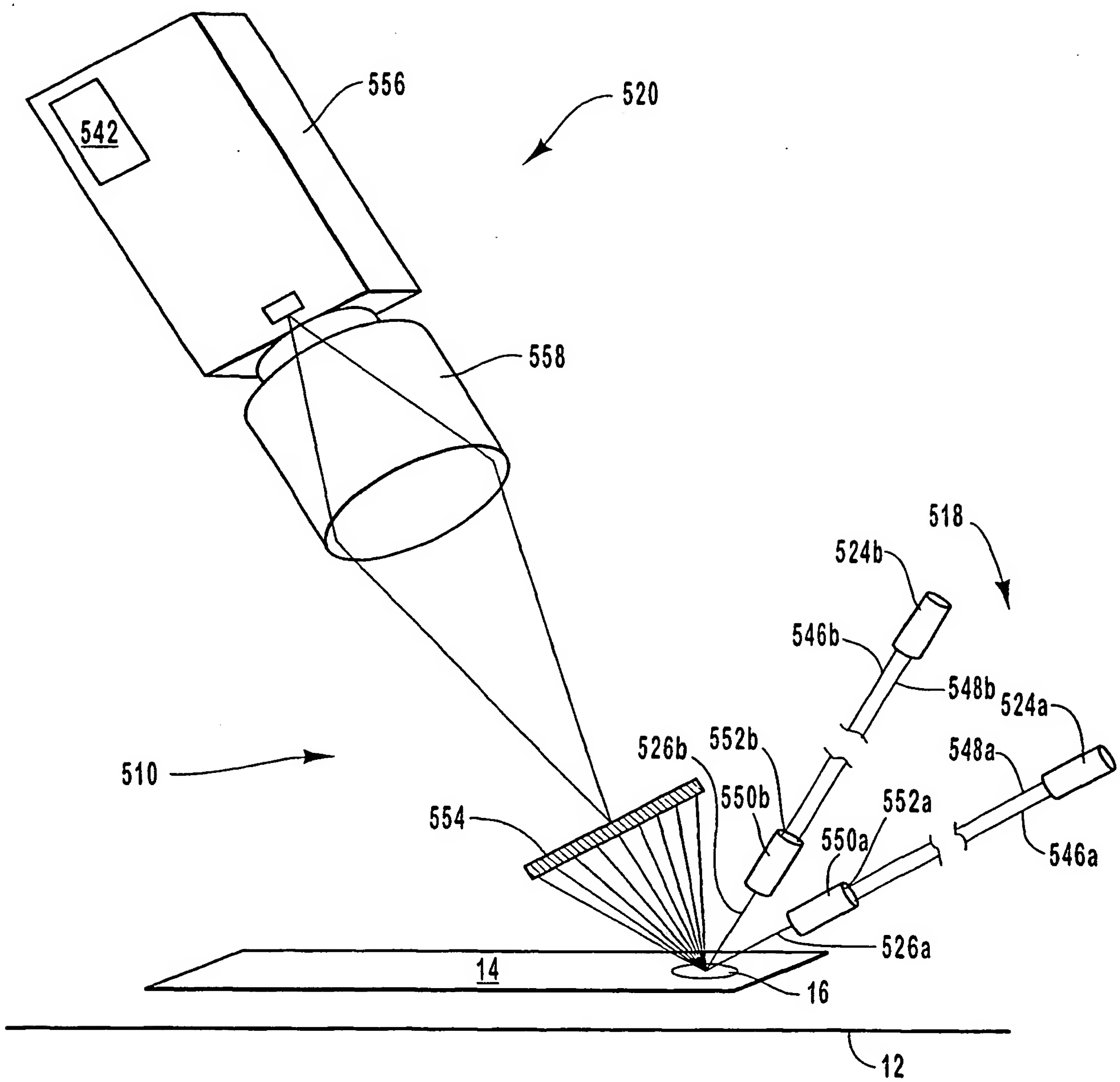


FIG. 11


556
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542
558
518
524b
546b
548b
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526b
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548a
554
550b
552a
550a
546a
526a
14
16
12

FIG. 12

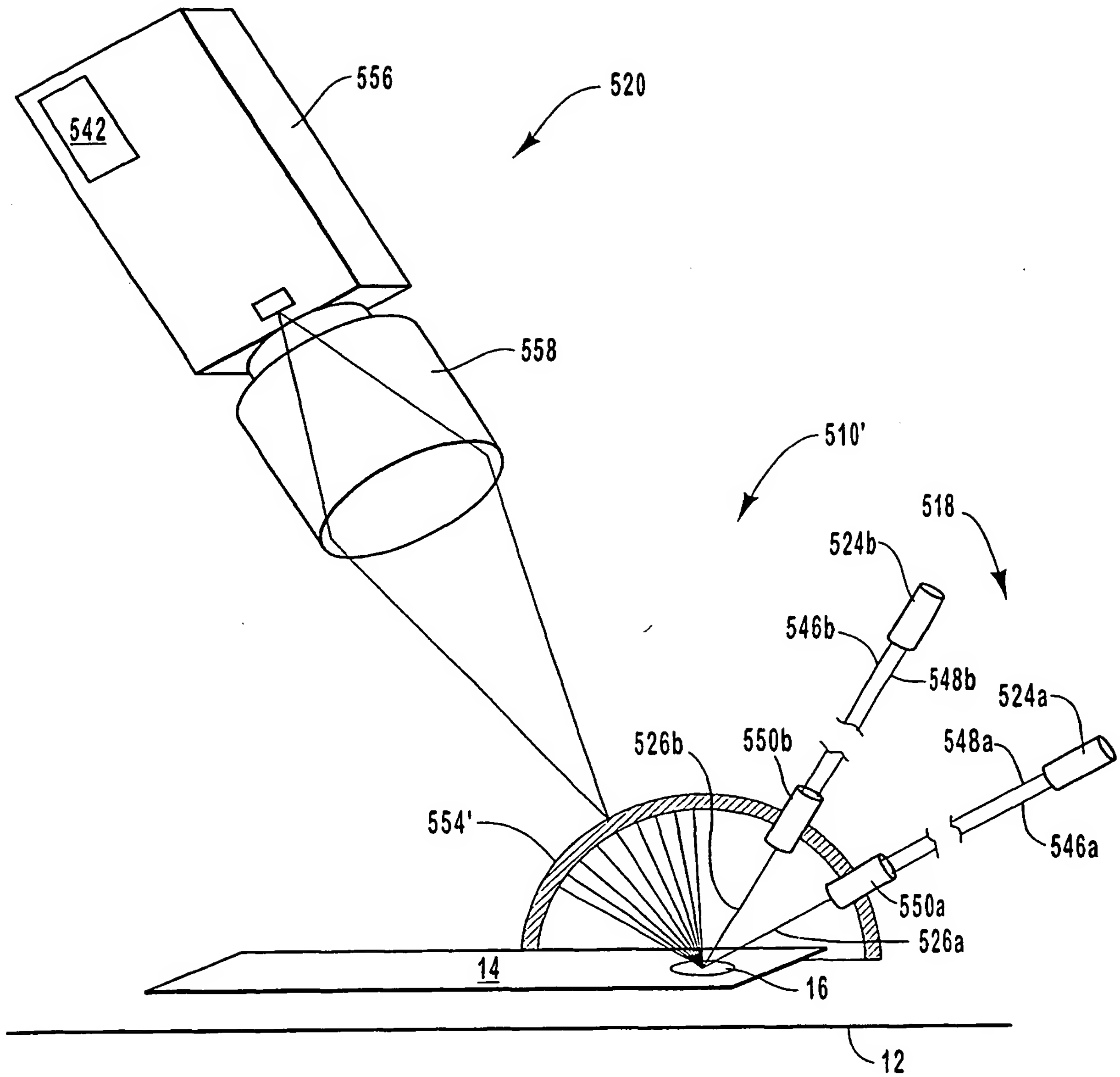
556
520
542
558
510'
518
524b
546b
548b
524a
526b
550b
548a
554'
546a
550a
526a
14
16
12

FIG. 13

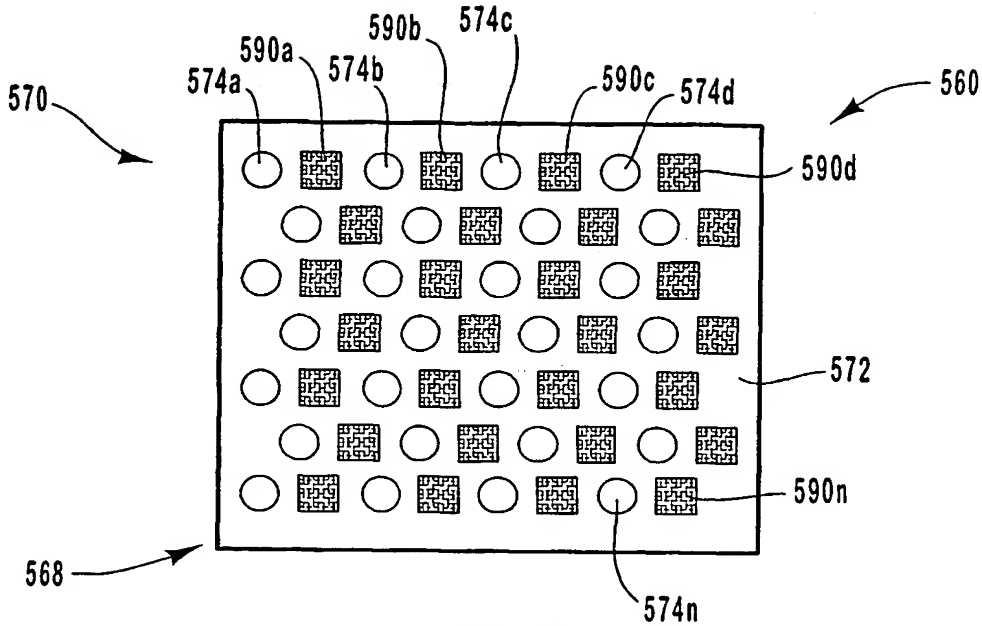
570
574a
590a
574b
590b
574c
590c
574d
560
590d
572
590n
568
574n

FIG. 14

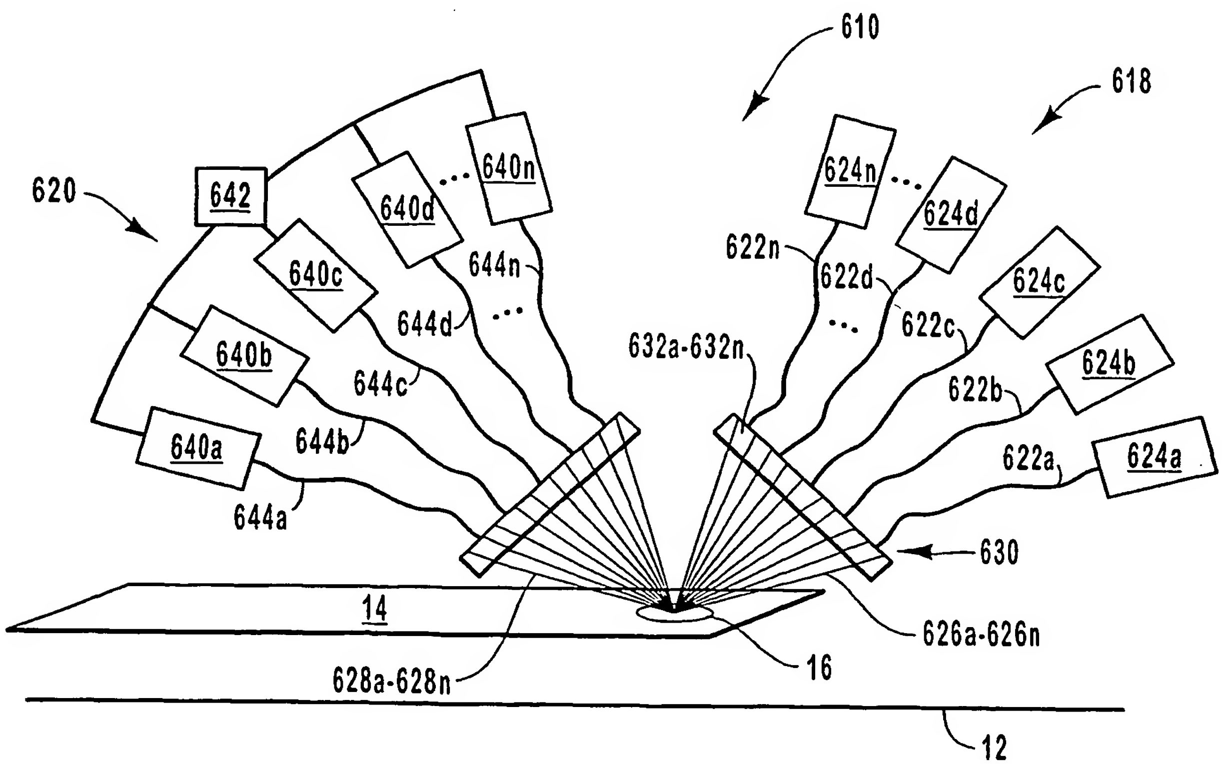
610
618
620
642
640n
640d
640c
640b
640a
644n
644d
644c
644b
644a
624n
624d
624c
624b
624a
622n
622d
622c
622b
622a
632a-632n
630
14
626a-626n
16
628a-628n
12

FIG. 15

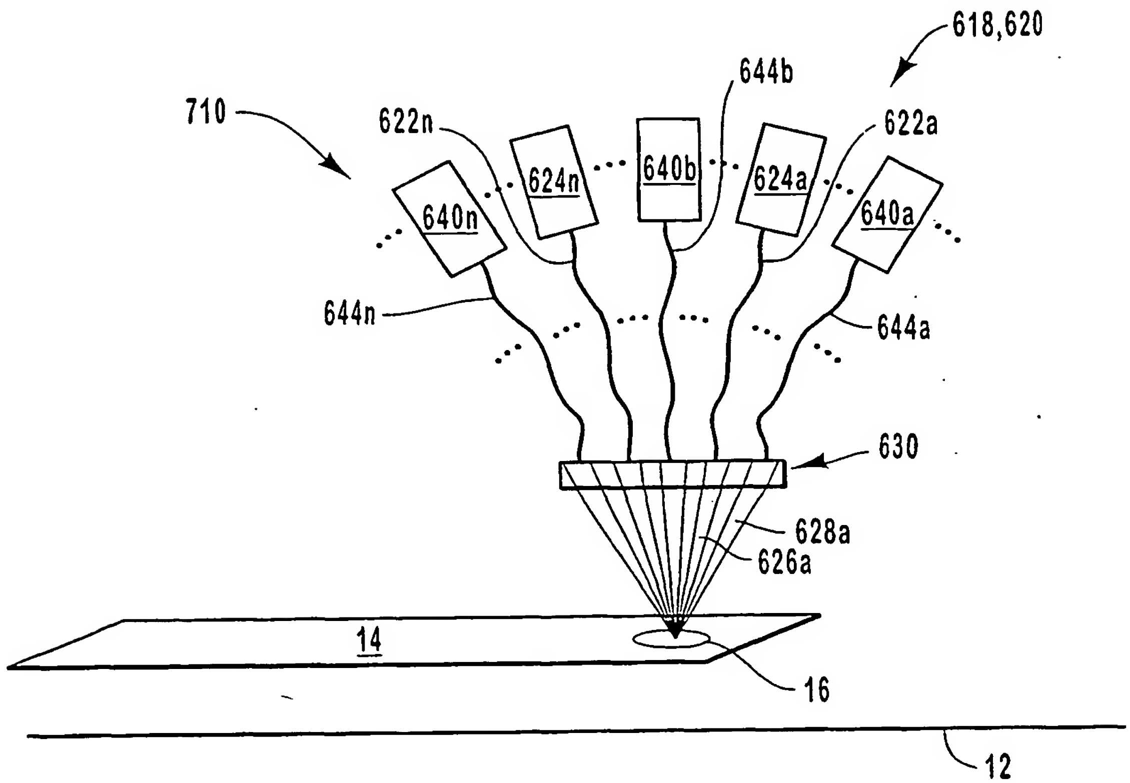
618,620
710
622n
644b
622a
640n
624n
640b
624a
640a
644n
644a
630
628a
626a
14
16
12

FIG. 16

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 00/28030

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G07D7/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B41M G07D C09C C09D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	PAUL G. COOMBS AND TOM MARKANTES: "Improved verification methods for OVI security ink" SPIE, vol. 3973, 2000, pages 296-303, XP000981521 abstract page 300, paragraph 2 -page 303, paragraph 1 ---	1-91
X	WO 96 13801 A (FLEX PRODUCTS INC) 9 May 1996 (1996-05-09) abstract page 6, line 29 -page 7, line 20	1,4,79, 82
A	page 10, line 27 -page 11, line 31 figures 2-5 ---	2,3, 5-78,80, 81,83-91

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
28 February 2001	14.03.2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Van Dop, E

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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A	abstract column 4, line 45 - line 56 column 5, line 37 - line 58 column 6, line 61 -column 7, line 38 figure 8	1-28,30, 36-41, 44,49-91
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